Working from home: Too much of a good thing?*

Kristian Behrens† Sergey Kichko‡ Jacques-François Thisse§

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Abstract

We develop a general equilibrium model to study how different intensities of telecommuting affect firms' efficiency and the economy as a whole. We pay attention to the effects of working from home (WFH) that operate through changes in the production and consumption of buildings: more WFH reduces firms' demands for office space, but increases workers' demand for space at home. WFH is a mixed blessing: the relationship between telecommuting and GDP is ∩-shaped, and more WFH raises income inequality. Thus, an excessive downscaling of workspaces may be damaging to all. Firms and workers are shown to generally choose inefficiently large WFH shares.

Keywords: working from home; alternative work arrangements; telecommuting; housing and office markets; land.

JEL Classification: J20, R13, R14.

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†Department of Economics, Université du Québec à Montréal (Canada); HSE University (Russian Federation) and CEPR. E-mail: behrens.kristian@uqam.ca

‡HSE University (Russian Federation). E-mail: sergey.kichko@gmail.com

§CORE-UCLouvain (Belgium); HSE University (Russian Federation) and CEPR. E-mail: jacques.thisse@uclouvain.be

1 Introduction

Since widespread telecommuting may become a permanent feature of the economic landscape, our societies might experience a systemic shock whose consequences are unclear. The core goal of this paper is to study how different intensities of telecommuting affect the efficiency of firms that embrace working from home (WFH), as well as its impact on workers' well-being and the economy as a whole. Previewing our key findings, we show that working from home (WFH) is generally better than to no WFH at all. Yet, an excessive downscaling of workspaces may be damaging to the entire economy when the new information and communication technologies (ICT) are not sufficiently efficient. WFH also exacerbates inequality between the skilled and the unskilled. Thus, *telecommuting is a mixed blessing.*

If the literature in management and psychology devoted to telecommuting is vast, the economics literature on that topic is relatively meager. While there are a number of empirical contributions that study the impact of telecommuting on productivity, theoretical papers are few and far between.[1] Our study aims to partly fill this gap by providing a general equilibrium model in which we can trace out the possible long-run effects of WFH.

What are the main features our setting needs to take into consideration? First, it is a robust empirical fact that WFH affects the skilled and the unskilled differently. Although there are exceptions (think of call-centers), telework characterizes predominantly skilled workers (Dingel and Neiman, 2020; Adams-Prassl *et al.*, 2020). This point has been amply scrutinized during the recent COVID pandemic. Hence, to trace out the productivity and distributional effects of WFH, we need a model with workers who can and workers who cannot work from home.[2]

Second, by its very nature, telecommuting is bound to have profound effects on labor

[1] Safirova (2002) and Rhee (2008) are exceptions. The former author extends the monocentric city model to account for telecommuting when home workers and office workers are imperfect substitutes, yet remains within standard urban economics by considering a land market and a single sector producing the consumption good. Moreover, she provides only numerical solutions. The latter author studies the trade-off between working time and leisure and shows that most of the commute time saved by WFH is allocated to work rather than leisure.

[2] Dingel and Neiman (2020) observe that the 37 percent of US jobs that can be performed at home pay more than those that have to be performed in the workplace. Adams-Prassl *et al.* (2020) find that workers with a university degree can do a significantly higher share of their work tasks from home. According to Bartik *et al.* (2020), there seems to be less productivity loss from remote working in the case of educated and well-paid workers.

and housing markets. Stanton and Tiwari (2021) show that prior to the pandemic, wired workers needed more space at home to accomplish their tasks (which affects location choices and the residential construction sector), while firms' space requirements are strongly reduced (which also affects location choices and the office construction sector). The very recent trend toward more suburbanization in several US metropolitan areas suggests that the additional demand for space is key in the residential choices made by a growing number of households (Gupta *et al.*, 2021; Liu and Su, 2021; Brueckner *et al.*, 2021). As a result, the markets for land and buildings must occupy center stage in a work that aims to assess the global effects of telework.

Studying how the above effects interact to shape the economy requires a *general equilibrium* setting. Given the central role of the land and building markets, we also need a better understanding of how locales with different land and building supply elasticities are affected. To achieve this goal, we develop a model with three primary production factors—land, skilled, and unskilled labor—and three sectors—the construction sector that supplies buildings to firms and workers, and the intermediate sector that supplies an endogenous range of inputs to the final sector, which itself produces the consumption good. Skilled workers can work home a variable share of their time.

Our key results can be summarized as follows. First, the effects of WFH are described by bell-shaped curves: telecommuting first increases GDP (and skilled and unskilled workers' productivity) up to some threshold, whereas it starts to decrease productivity and GDP when there is excessive downscaling of office space. Indeed, a relatively small share of home-workers allows one to exploit more intensively the potential of ICT. However, beyond some level, a higher share of home-workers becomes less efficient for the current development of ICT. In the same vein, there is first more and, then, less diversity in the intermediate sector. Assuming that the number of intermediate firms reflects the efficiency of the innovation system as in Romer's endogenous growth models, this result suggests that *too much WFH may be detrimental to long-run innovation and growth.* This finding echoes what OECD (2020) suggests in its report on the possible long-run consequences of increased telework.

Second, though an intermediate WFH share is desirable, we do not know where the top of the bell is. Some back-of-the-envelope computations using consensus parameter values suggest the WFH share that maximizes GDP varies between 30 and 65 percent (two to three working days per 5-day week) in our model. This is broadly in line with the empirical evidence collected by Barrero *et al.* (2020) who find that about 22 percent of workdays are likely to be supplied from home after the pandemic, as well as with recommendations made in human resource management (see, e.g., Gajendran and Harrison, 2007). We show that these results are robust to including additional realistic features such as reduced congestion (as workers need to commute less) and less-than-perfect substitutability between office buildings and residential housing.

Third, whether WFH has positive or negative consequences for workers depends on the interplay between the WFH share, the efficiency of ICT, and the land supply elasticity: when ICT are not very efficient, workers are better off when the WFH share remains relatively small. This may explain why WFH has not yet been implemented on a large scale. Furthermore, a less elastic supply of land increases housing prices and makes WFH more expensive as wired workers need to acquire larger residences. WFH and the shifting demand of residential and office space are likely to have the largest effects in cities with weak land-use regulations. This provides a neat and simple general equilibrium foundation to various works which report that excessive land use regulation were damaging to the economy at a time when the WFH share was small (Hilber and Vermeulen, 2014; Cheshire *et al.*, 2015; Hsieh and Moretti, 2019).

Last, it is profit-maximizing for firms to implement a partial WFH strategy. Yet, if firms are free to non-cooperatively choose their level of WFH *the equilibrium WFH share is larger than the one that maximizes the GDP*. This is because firms disregard the positive externality that a larger number of intermediates has on the final sector. If workers are free to choose their WFH share, we show that they will either choose full time office or full time home work. The precise choice they make crucially depends on initial conditions. An exogenous shock such as the COVID pandemic may change workers' choice and shift the economy between different equilibria, thus serving as a coordination device. However, there is no guarantee that the chosen equilibrium is the best one, i.e., there is scope for workers being caught in a prisoner's dilemma.

The remainder of our paper is organized as follows. The model is presented in Section 2, with a special attention to the intermediate sector that implements the alternative work arrangements. In Section 3, we prove the existence and uniqueness of an equilibrium. Section 4 is devoted to the various implications of telecommuting for the three sectors, the two groups of workers, and GDP. We also illustrate the quantitative implications of the model using consensus parameter values from the literature. In Section 5 we discuss the equilibrium WFH share chosen by firms and by workers and show how the choices differ. Last, Section 6 concludes.

2 The model

We consider an economy that produces three goods: (i) a homogeneous consumption good, x; (ii) a continuum of differentiated intermediate inputs, $q(i)$, used to produce x; and (iii) buildings, B. The intermediate sector operates under monopolistic competition and increasing returns, while the other two sectors produce under perfect competition and constant returns. Buildings are consumed as either housing by workers or as inputs—plants and offices—by the intermediate and final sectors. There are three primary production factors—land $\mathcal{L}$, skilled labor s (e.g., management, professional, and related occupations) and unskilled labor ℓ (e.g., construction- and assembly-line workers). The city is divided into two areas; a *residential district*, where all workers live; and a *business district*, where all production takes place. Moving between the two districts is costly but moving within a district is costless. Land is used as an input by the construction sector only and is owned by a given population of landowners. Since firms and workers do not choose their locations, there is only one price for land. Shipping the consumption good from the business district to the residential district is costless, so that its price in the same in the two districts. The consumption good is chosen as the numéraire, and thus its price p_x equals 1.

2.1 Workers

The population is formed by workers and landowners. The mass of k-workers is given by L_k for type $k = \ell, s$. We assume that $L_\ell > L_s$. Each worker supplies inelastically one unit of her type of labor and consumes h_k units of housing and x_k units of the consumption good.

2.1.1 Skilled workers

Following the urban economics literature, we model commuting costs using an iceberg $\tau_k \geq 1$, which amounts to lowering the worker's income.[3] Since the opportunity cost of

[3]The empirical evidence confirms that individuals who have a longer commute are more prone to being absent from work, to arrive late at the workplace, and/or to make less

time increases with income (Small, 2012; Koster and Koster, 2015), it is reasonable to assume that commuting is more costly for the skilled, i.e., $\tau_s > \tau_\ell$. To alleviate notation, we normalize τ_ℓ to 1 and set $\tau_s \equiv \tau > 1$. This does not change our qualitative results.

Skilled workers can work at home (telecommuting) or in the office (commuting). When a skilled works home, she provides one efficiency unit of home-work; when she commutes to the workplace, she provides $1/\tau < 1$ efficiency units of office-work. Therefore, commuting is a pure social loss because it reduces individual labor supply. This loss increases with τ. Here lies the main social force that pushes toward telecommuting.

Furthermore, working at home requires additional space to perform professional tasks.[4] As a result, a skilled worker acquires more housing space than what she uses for personal consumption. Let $\rho \in [0, 1]$ denote the WFH share and $\bar{h}(\rho)$ the additional space needed for telework. In other words, when a wired worker buys h_s units of housing, $\bar{h}(\rho) > 0$ units are used for professional purposes and $h_s - \bar{h}(\rho)$ for private consumption. We hence model skilled workers' preferences by the following Stone-Geary specification:

$$U_s = \frac{1}{\gamma^\gamma (1-\gamma)^{1-\gamma}} \left(h_s - \bar{h}(\rho)\right)^\gamma x_s^{1-\gamma}, \tag{1}$$

with $\gamma \in (0, 1)$. We assume that $\bar{h}(\rho) = k\rho^\theta$ where $\theta > 0$ is small while $0 < k < 1$. Hence, $\bar{h}(\rho)$ increases rapidly when the worker starts to work home and expands less with the time she spends home.[5] In what follows, we suppress the argument ρ when there is no possible confusion.

A skilled worker's budget constraint is given by $p_b h_s + x_s = w_s$, where p_b is the unit price of housing and w_s is the skilled wage, which depends on the home-office split of work. Formally, given our assumptions on commuting costs, $w_s = \rho\omega_s + (1-\rho)\omega_s/\tau$, where ω_s is the shadow price of one efficiency unit of skilled labor. Maximizing (1) subject to that constraint yields the following demands for housing

work effort (van Ommeren and Gutiérrez-i-Puigarnau, 2011). According to BLS data (https://www.bls.gov/news.release/cesan.nr0.htm), Americans spent about 16-17% of their income on transportation in 2019. This includes all expenses, not just commuting. Mas and Pallais (2017) find that American workers are willing to give up 8 percent of their wage for the option of WFH, thus suggesting that commuting likely represent a large share of the total transportation budget.

[4] Bloom (2020) finds that only 49 percent of respondents can work in a room other than their bedroom. Thus, in the long run, working from home requires additional space for professional tasks.

[5] Alternatively, we could model the space used for home office as a fixed cost. In that case, $\bar{h}$ is discontinuous at zero. Doing so complicates the analysis and does not add much additional insight.

and the consumption good:

$$h_s = \gamma \frac{w_s}{p_b} + (1-\gamma)\bar{h}, \quad \text{and} \quad x_s = (1-\gamma)\left(w_s - p_b \bar{h}\right), \tag{2}$$

which both depend on $\bar{h}$. The foregoing expressions show that a skilled who works at home buys $(1-\gamma)\bar{h}(\rho)$ units more housing space than when she is an office worker. However, her demand for housing used for personal consumption, $h_s - \bar{h}(\rho)$, is shifted downward with $\bar{h}$. In addition, she also buys a smaller quantity of the consumption good than when she works in the office. In other words, *a higher WFH share incentivizes the wired workers to buy more space but to consume less of it.*

Plugging the demand functions (2) into (1) yields the indirect utility:

$$V_s = \frac{w_s - p_b \bar{h}}{p_b^{\gamma}}, \tag{3}$$

which decreases with $\bar{h}$. In other words, the direct effect of telecommuting is to reduce skilled workers' welfare because less housing space is available for private consumption.

2.1.2 Unskilled workers

We assume that the unskilled workers' activities must be completely undertaken within production facilities located in the business district. In other words, we have $\rho = 0$, hence $\bar{h} = 0$, so that unskilled workers' preferences are Cobb-Douglas:

$$U_\ell = \frac{1}{\gamma^\gamma (1-\gamma)^{1-\gamma}} h_\ell^\gamma x_\ell^{1-\gamma}. \tag{4}$$

Since commuting costs for the unskilled are normalized to 1, the unskilled wage w_ℓ is equal to the price of a unit of unskilled labor. As a result, an unskilled worker's budget constraint is $p_b h_\ell + x_\ell = w_\ell$, so that demands are given by

$$h_\ell = \gamma \frac{w_\ell}{p_b}, \quad \text{and} \quad x_\ell = (1-\gamma) w_\ell. \tag{5}$$

Last, plugging the demand functions (5) into (4) yields the indirect utility:

$$V_\ell = \frac{w_\ell}{p_b^{\gamma}}. \tag{6}$$

2.1.3 Landowners

Landowners' income is given by the total rent they collect from the construction sector that uses land as an input. Since landowners often account for a small share of the total population, we assume for simplicity that their housing consumption is negligible, i.e., landowners consume only the final good. Let r denote the price of one unit of land. Then, aggregate income of landowners is equal to the aggregate land rent $ALR = r\mathcal{L}$, which also equals their aggregate demand for the final good.

2.2 Production

We next turn to the production side of the economy.

2.2.1 Buildings

The demand for buildings stems from three types of buyers: (i) consumers; (ii) the final sector; and (iii) intermediate firms. Although housing, plants, and offices are different types of buildings, we assume for simplicity that they can be used equally by workers, the intermediate, and the final sectors. Put differently, we assume that buildings are *perfectly fungible*. We relax this simplifying assumption in Section 4.4 and show that our qualitative results are robust when the different building types are imperfect substitutes.

According to Glaeser *et al.* (2005), the construction sector is almost perfectly competitive. Following Combes *et al.* (2016), we assume that the production function for buildings is of the Cobb-Douglas form $B = \delta^{-\delta}(1-\delta)^{-(1-\delta)}\mathcal{L}^{\delta}L_b^{1-\delta}$, where B is the output of the construction sector, δ denotes the cost share of land, $\mathcal{L}$ is the quantity of developed land, and L_b is the total amount of unskilled labor employed in the construction sector.[6] Hence, the marginal production cost equals

$$c_b = r^{\delta}w_{\ell}^{1-\delta}.$$

Even when the total amount of available land, $\mathcal{L}$, is fixed, the total amount of buildings is endogenous because land and unskilled labor are substitutes. In particular,

[6]We could add capital to the model and assume that its supply is perfectly elastic at a given price determined in the national market. Doing so amounts to adding constant terms to the model and leaves our insights unchanged.

when demand for buildings, B, rises more workers are employed in the construction sector. The land rent is determined by the land market clearing condition:

$$B\frac{\partial c_b}{\partial r} = \mathcal{L}, \tag{7}$$

where $\partial c_b/\partial r$ is the amount of land required to produce one unit of building.

In what follows, we assume that the amount of land available for development increases with the output of the construction sector at a given elasticity $\mu \in [0, 1]$, i.e., a higher demand for buildings allows more land to be developed:

$$\mathcal{L} = B^{\mu}. \tag{8}$$

A low value of μ means an inelastic land supply like in areas characterized by strong land-use regulations (Glaeser *et al.*, 2005) or difficult topography (Saiz, 2010). A high value of μ means that the land supply is elastic, perhaps because there is still a large amount of undeveloped land or because land-use regulation is lax. In the limit, when $\mu = 1$ the land supply is perfectly elastic. The value of μ reflects the scarcity of developable land (Saiz, 2010), the restrictiveness of land use regulations (Glaeser *et al.*, 2005), or both.

Equalizing (7) and (8) yields $\delta\left(w_\ell/r\right)^{1-\delta} B = B^{\mu}$, which can be solved for the equilibrium land rent as a function of the construction sector's output:

$$r = \delta^{\frac{1}{1-\delta}} w_\ell B^{\frac{1-\mu}{1-\delta}}. \tag{9}$$

Combining (8) and (9) yields the land supply function $\mathcal{L}(r) = [(1/\delta)\left(r/w_\ell\right)^{1-\delta}]^{\mu/(1-\mu)}$. The latter increases with the land rent when $\mu \in (0, 1)$ and its elasticity increases with μ.

Perfect competition in the construction sector implies that price equals marginal cost:

$$p_b = w_\ell^{1-\delta} r^{\delta} = \delta^{\frac{\delta}{1-\delta}} w_\ell B^{\frac{(1-\mu)\delta}{1-\delta}}. \tag{10}$$

Using this expression, we can compute the aggregate land rent that accrues to the landowners as follows:

$$ALR = r\mathcal{L} = \delta B p_b. \tag{11}$$

To sum up, both the price of buildings and the price of land increase with the output B when $\mu < 1$. By contrast, when the land supply is perfectly elastic ($\mu = 1$), p_b and r are independent of B because the demand for land is exactly matched by an increase in land supply.

As all types of buildings are perfectly fungible, we have $B = B_h + B_I$, where $B_h = L_\ell h_\ell + L_s h_s$ is the total housing demand, while B_I is the demand for buildings stemming from the intermediate sector.

2.2.2 Consumption good

The final sector produces a homogeneous consumption good, x, under constant returns and perfect competition using a CES bundle of intermediate inputs. The production function of this sector is given by

$$Y = \left[\int_0^M q(i)^{\frac{\sigma-1}{\sigma}} \mathrm{d}i\right]^{\frac{\sigma}{\sigma-1}}.$$

In this expression, Y is the total output of the final sector, $q(i)$ is the quantity of intermediate input i, $\sigma > 1$ is the elasticity of technological substitution between intermediates, and M is the mass of inputs produced by the intermediate sector.

Given this production function, the marginal production cost in the final sector is given by

$$c_x = \mathbf{P}, \quad \text{where} \quad \mathbf{P} = \left[\int_0^M p(i)^{1-\sigma} \mathrm{d}i\right]^{\frac{1}{1-\sigma}} \tag{12}$$

is the price index of intermediate inputs and $p(i)$ the price of variety i. Because of perfect competition and our choice of numéraire, we have $c_x = p_x \equiv 1$. As usual in this type of model, there are increasing returns to scale in the final sector with respect to the range of intermediate goods.[7]

2.2.3 Intermediate inputs

Turning to the intermediate sector, it produces *a continuum of horizontally differentiated varieties* using skilled labor, unskilled labor, and buildings. Each variety is supplied by a single firm. In line with trade and endogenous growth models, we

[7]Indeed, assuming that $p(i) = p$ for all i and holding expenditures on intermediates, $E_I = Mpq$ fixed, the price index equals $\mathbf{P} = M^{\frac{1}{1-\sigma}} \frac{E_I}{Mq} = M^{\frac{\sigma}{1-\sigma}} \frac{E_I}{q}$, thus showing that marginal cost $c_x = M^{\frac{\sigma}{1-\sigma}} E_I/q$ is decreasing in the range of intermediates M.

assume that a firm hires skilled workers to design a particular intermediate input, called a variety. Afterwards, each firm produces that variety using unskilled labor and buildings.

Fixed costs. To design an intermediate input, a firm requires a fixed amount $F > 0$ of efficiency units of skilled labor. Given the labor arrangement ρ, when an intermediate firm hires L_I skilled workers, it secures ρL_I units of home labor and $[(1-\rho)/\tau]L_I$ units of office labor where $1/\tau < 1$ is the labor efficiency loss due to commuting to the office. In what follows, we assume that home labor (L_h) and office labor (L_o) are imperfect substitutes. More specifically, combining $L_h = \rho L_s$ units of home labor and $L_o = (1-\rho)L_s$ units of office labor translates into $f(L_h, L_o)$ efficiency units of skilled labor. We assume that the function f satisfies the standard neoclassical assumptions: it is strictly positive, homogeneous of degree one with $f_1 > 0$, $f_{11} < 0$, $f_2 > 0$, $f_{22} < 0$ and $f_{12} > 0$. Thus, we have

$$f(L_h, L_o) = f(\rho L_I, ((1-\rho)/\tau)L_I) = L_I f(\rho, (1-\rho)/\tau) \equiv L_I A(\rho).$$

Observe that since $f > 0$, neither input is essential. By differentiating twice $A(\rho)$ and using the properties of f, it is readily verified that $A(\rho)$ is strictly concave over $[0,1]$. This function thus has a single maximizer $\rho_M \in [0,1]$. We also assume that $A(\rho)$ increases at $\rho = 0$ and decreases at $\rho = 1$, for otherwise $A(\rho)$ is monotone increasing or decreasing over $[0,1]$. These two assumption are plausible because ICT have reached a sufficiently high level of development for workers to perform some tasks remotely. For example, before the pandemic, the average WFH share in the European Union was 5.1 percent (Eurostat, 2020). By contrast, the on-going ICT are not sufficiently efficient for $A(\rho)$ to be increasing over the whole interval $[0,1]$. In sum, the function $A(\rho)$ is strictly positive and strictly concave over the interval $[0,1]$ with a maximizer at $\rho_M \in (0,1)$. Intuitively, this amounts to assuming that *a very large or a very small mass of teleworkers is inefficient* from the firm's perspective. All these properties hold when $A(\rho)$ is given by a CES function.

Recall that an intermediate firm requires F efficiency units of skilled labor to develop its variety. Hence, since $F = f(L_h, L_o)$, an intermediate firm hires a mass of skilled workers L_I given by

$$L_I(\rho) = \frac{F}{A(\rho)}. \tag{13}$$

Since $A(\rho)$ is single-peaked, $L_I(\rho)$ is a $\cup$-shaped function of ρ. That is, L_I first decreases until $\rho = \rho_M$ and then increases with the WFH share.

An intermediate firm must provide each skilled worker employed at the office with one unit of office space. Skilled labor employed at home requires zero units of office space (from the firm's perspective). Therefore, *office labor and office space are complements*. An increase in ρ thus allows an intermediate firm to reduce its space usage. For example, if workers come only 50 percent of the time to the office, they can share offices with others, which reduces the need for office space by half. This is especially important in locations commanding high rents, e.g., the downtowns of large cities or tech clusters. Since skilled workers are allocated with shares $1 - \rho$ and ρ to office work and to home work, the full price paid by the firm for one skilled worker equals $(1 - \rho)p_b + w_s$. For given price p_b and wage w_s, the fixed cost borne by the intermediate firm i is thus given by

$$FC_I = [(1 - \rho)p_b + w_s] \frac{F}{A(\rho)},$$

where we have used (13). Hence, the fixed cost decreases with the WFH share and increases with commuting costs. As a result, expensive office spaces naturally incentivize firms to decentralize their skilled jobs.

Production costs and profits. Once variety i has been developed using skilled labor and office space, producing it in a plant requires unskilled labor and buildings according to a Cobb-Douglas production function. The variable production cost of firm i is given by:[8]

$$VC_I(q(i)) = w_\ell^{1-\alpha} p_b^\alpha q(i).$$

Using (12), the aggregate demand $q(i)$ for variety i stems from the final sector and is given by

$$q(i) = Y \frac{\partial c_x}{\partial p(i)} = Y \mathbf{P}^{\sigma-1} p(i)^{-\sigma}. \tag{14}$$

Firm i treats Y and $\mathbf{P}$ parametrically because it is negligible in the sense that its actions have no impact on the market. As a result, the total production cost of firm i

[8]We assume, without loss of generality, that units for the output of varieties are choosen for firms' total factor productivity to equal one. Furthermore, as our model omits capital, we consolidate building and capital within a single input.

is given by

$$C_I(i) \equiv VC_I(q(i)) + FC_I = w_\ell^{1-\alpha} p_b^\alpha q(i) + [(1-\rho)p_b + w_s]\,\frac{F}{A(\rho)}, \tag{15}$$

so that its profit function is as follows:

$$\pi_I(i) = \left[p(i) - w_\ell^{1-\alpha} p_b^\alpha\right] \beta Y \mathbf{P}^{\sigma-1} p(i)^{-\sigma} - [(1-\rho)p_b + w_s]\,\frac{F}{A(\rho)},$$

where we have used (14). The profit function shows how firms can save on space to reduce their real estate costs.

Price and firm size. Maximizing profits with respect to $p(i)$, and noting that firms are symmetric, yields the equilibrium price set by intermediate firms

$$p = \frac{\sigma}{\sigma - 1} w_\ell^{1-\alpha} p_b^\alpha. \tag{16}$$

Thus, the price index of the intermediate sector equals

$$\mathbf{P} = M^{\frac{1}{1-\sigma}} p = \frac{\sigma}{\sigma-1} M^{\frac{1}{1-\sigma}} w_\ell^{1-\alpha} p_b^\alpha. \tag{17}$$

Using (16) and (17), operating profits are given by $\Pi(p) \equiv \left(p - w_\ell^{1-\alpha} p_b^\alpha\right) Y \mathbf{P}^{\sigma-1} p^{-\sigma} = Y/(\sigma M)$. In line with trade and geography models, we assume that the skilled are the residual claimants, so that a firm's residual profits, $\Pi(p) - L_I(1-\rho)p_b$, are redistributed to these workers. Therefore, the equilibrium skilled wage w_s solves the zero-profit condition:

$$w_s = \frac{Y}{\sigma L_s} - (1-\rho)p_b. \tag{18}$$

The direct effect of WFH is thus to raise the skilled wage. We will see below what happens when we account for the endogeneity of the output Y of the final sector and the price p_b of buildings. The equilibrium profits in the construction and final sectors are equal to zero because they operate under perfect competition and constant returns. Hence, total profits in the economy are equal to zero too.

Furthermore, plugging (16) and (17) into (14) and using the market clearing condition for variety i imply that firm i's equilibrium output is given by

$$q(\rho) = \frac{\sigma - 1}{\sigma} w_\ell^{\alpha-1} p_b^{-\alpha} \frac{Y}{M(\rho)}. \tag{19}$$

A firm's size thus depends on the WFH share ρ.

3 Equilibrium

We now establish the equilibrium conditions and solve for the equilibrium of the model.

Mass of intermediate firms. Since each intermediate firm requires L_I units of skilled labor, labor market clearing implies that skilled labor demand, ML_I, equals skilled labor supply, L_s. The equilibrium mass of intermediate firms is thus equal to

$$M^*(\rho) = A(\rho) \frac{L_s}{F}, \tag{20}$$

which decreases with the level of commuting cost τ because each firm must hire a larger mass of skilled workers.

Unskilled labor. Recall that unskilled labor is used by the construction- and intermediate sectors. Hence, the unskilled labor market clearing condition is given by

$$L_\ell = B \frac{\partial c_b}{\partial w_\ell} + M \frac{\partial VC_I}{\partial w_\ell}.$$

Using the cost functions VC_I and c_b defined above yields:

$$L_\ell = (1 - \delta) r^\delta w_\ell^{-\delta} B + (1 - \alpha) p_b^\alpha w_\ell^{-\alpha} M q.$$

By implication of (12), (18), (19), and (9), the market clearing condition for the unskilled can be rewritten as follows:

$$w_\ell L_\ell = (1 - \delta) B p_b + (1 - \alpha) \frac{\sigma - 1}{\sigma} Y. \tag{21}$$

Buildings. Using (15), we obtain the demand for buildings stemming from the intermediate sector:

$$B_I = M\frac{\partial C_I}{\partial p_b} = M(1-\rho)L_I + \alpha M q\left(\frac{w_\ell}{p_b}\right)^{1-\alpha}.$$

Using (20), and (19), this expression becomes:

$$B_I = (1-\rho)L_s + \alpha\frac{\sigma-1}{\sigma}\frac{Y}{p_b}. \tag{22}$$

Market clearing in the construction sector implies $B = B_h + B_I$. Using (2) and (5) yields the total output of the construction sector:

$$B = \underbrace{\gamma\frac{w_\ell L_\ell + w_s L_s}{p_b} + (1-\gamma)\bar{h}L_s}_{\text{residential demand } (B_h)} + \underbrace{(1-\rho)L_s + \alpha\frac{\sigma-1}{\sigma}\frac{Y}{p_b}}_{\text{commercial demand } (B_I)},$$

where $(1-\gamma)\bar{h}L_s$ is the additional demand for housing generated by WFH, while $(1-\rho)L_s$ is the demand for offices that stems from the intermediate firms.

Multiplying the foregoing expression by p_b, we obtain the total value of buildings:

$$Bp_b = \gamma(w_\ell L_\ell + w_s L_s) + \alpha\frac{\sigma-1}{\sigma}Y + p_b\left[(1-\gamma)\bar{h} + 1 - \rho\right]L_s. \tag{23}$$

Consumption good. Plugging (17) into (12) and recalling that $p_x \equiv 1$, we obtain the following condition for profit maximization in the final sector:

$$\frac{\sigma}{\sigma-1}M^{-\frac{1}{\sigma-1}}w_\ell^{1-\alpha}p_b^{\alpha} = 1. \tag{24}$$

Using (2), (5), and (11), market clearing for the consumption good requires that:

$$Y = (1-\gamma)\left[w_\ell L_\ell + \left(w_s - p_b\bar{h}\right)L_s\right] + \delta B p_b. \tag{25}$$

An equilibrium is given by prices and quantities $\{p_b, p, w_\ell, w_s, q(i)_{i\in[0,M]}, M, B, Y\}$. We show in Appendix A.1 that equations (10), (20), (21), and (23)-(25) can be reduced to the following equilibrium system in the three unknowns B, w_ℓ, and w_s:

$$B^{\frac{1-\delta\mu}{1-\delta}} = \Psi(\bar{h}+1-\rho)L_s B^{\frac{(1-\mu)\delta}{1-\delta}} + \delta^{-\frac{\delta}{1-\delta}} \frac{\gamma\sigma + \alpha(1-\gamma)(\sigma-1)}{\Gamma} L_\ell \tag{26}$$

$$1 = \delta^{\frac{\alpha\delta}{1-\delta}} \frac{\sigma}{\sigma-1} M^{-\frac{1}{\sigma-1}} B^{\frac{(1-\mu)\alpha\delta}{1-\delta}} w_\ell \tag{27}$$

$$\frac{w_s}{w_\ell} = \frac{1-(1-\delta)\gamma}{\Gamma}\frac{L_\ell}{L_s} - \frac{\delta^{\frac{\delta}{1-\delta}} B^{\frac{(1-\mu)\delta}{1-\delta}}}{\Gamma}\left[(1-\delta)(1-\gamma)\bar{h} + \left((1-\delta)(1-\gamma)+\Gamma\right)(1-\rho)\right] \tag{28}$$

where

$$\Gamma \equiv (1-\delta)\gamma + (1-\alpha\delta)(\sigma-1) > 1, \quad \Psi \equiv \tfrac{(1-\gamma)(1-\alpha)(\sigma-1)}{\Gamma} > 0$$

are positive bundles of parameters that are independent of ρ, ε, μ, and τ used in our comparative statics analyses below.

As shown in Appendix A.1, equations (26)–(28) yield a unique solution from which we can uniquely reconstruct all equilibrium prices and quantities. The following proposition summarizes our result.

Proposition 1 *The model always has a unique equilibrium.*

We further show in Appendix A.2 that, provided L_ℓ/L_s is large enough, there is a skill premium, i.e., $w_s > w_\ell$. In what follows, we assume that this is satisfied based on empirical grounds.

4 The bell-shaped curves in home-working

We are now equipped to study the impact of our key parameters, the WFH share, ρ, and the elasticity of land supply, μ, on the market outcome. How does WFH affect the equilibrium? How do these effects depend on the elasticity of land supply?

4.1 The effects of WFH

In this section, we determine how the main variables change in response to a shock that shifts the economy towards a higher WFH share, ρ.

Building output. The second term on the right-hand side of (26) is independent of ρ, whereas the first term shifts upwards with ρ when $\rho < \rho_B \equiv (k\theta)^{\frac{1}{1-\theta}}$ and, then, downward when $\rho > \rho_B$. Hence, for $\theta \in (0,1)$, the output of the construction sector first increases and, then, decreases with the WFH share. This result highlights one of the main trade-offs associated with telecommuting: a rising share ρ leads workers to buy more housing space, which pushes toward a higher output B, while firms purchase less office space, which pushes toward a smaller output B. The former effect overcomes the latter for $\rho < \rho_B$, the reason being that the increment in housing demand is high when ρ is small (recall that $\bar{h}'(0) \to \infty$). Once ρ is large enough, the opposite holds true because the additional housing consumption is small, whereas firms keep using less commercial buildings. Disregarding workers' additional needs for housing overestimates the welfare gains expected from telecommuting and implies that the output of the construction sector steadily decreases with the WFH share. Evaluating the full general equilibrium effect of telecommuting on the construction sector requires to consider that workers will demand more space in the long run to work from home. In sum, when ρ starts rising from 0, the additional demand for housing overcomes the lower demand for office. However, when $\rho > \rho_B$, the latter effect dominates the former. In the plausible case where θ and k take on a small value, ρ_B is small.

Mass of intermediate firms. It follows from (20) that M inherits the properties of $A(\rho)$. Since $A(\rho)$ is maximized at ρ_M, $M^*(\rho)$ is single-peaked with a unique maximizer at $\rho = \rho_M$. This WFH share supports the largest mass of intermediate inputs, which allows the final sector to reach its highest efficiency. In sum, *as the WFH share steadily rises, the efficiency of the final sector follows a bell-shaped curve.* While the demand for offices, $B_o = (1-\rho)L_s$, always decreases with ρ, a drop in office space is not sufficient to widen the range of intermediate inputs. This is because limitations in ICT prevents expansion of the intermediate sector beyond ρ_M.

To illustrate, consider the following example where $A(\rho)$ is given by a CES function:

$$A(\rho) = \left[\phi\rho^{\frac{\varepsilon-1}{\varepsilon}} + \left(\frac{1-\rho}{\tau}\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \qquad (29)$$

where $\varepsilon > 1$ is the elasticity of substitution between home and office workers. The parameter $\phi \in [0,1]$ captures the level of development of ICT that allow individuals to work from home instead of commuting to and working at the firm: more efficient ICT means a higher ϕ. The presence of a productive advantage associated with better infrastructure and other facilities in the business district reduces the value of ϕ. Hence, ϕ measures the efficiency of ICT *relative to* the efficiency of face-to-face communication. The works of Battiston *et al.* (2021) and Davis *et al.* (2021) suggest that the latter remains more efficient than the former.

Assume that ε is finite.[9] Since the elasticity of $A(\rho)$ is equal to

$$\mathcal{E}_\rho\left(A(\rho)\right) = \frac{\phi(\tau\rho)^{\frac{\varepsilon-1}{\varepsilon}} - \rho(1-\rho)^{-\frac{1}{\varepsilon}}}{\phi(\tau\rho)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\rho)^{\frac{\varepsilon-1}{\varepsilon}}}, \tag{30}$$

the function $A(\rho)$ is maximized at

$$\rho_M = \frac{\tau^{\varepsilon-1}}{\tau^{\varepsilon-1} + \left(\frac{1}{\phi}\right)^{\varepsilon}} < 1. \tag{31}$$

If ICT are relatively inefficient (ϕ is small), then ρ_M is small. However, ρ_M increases with the development of ICT and tends to 1 when ϕ is arbitrarily large. Expression (30) shows that $\mathcal{E}_\rho\left(A(0)\right) = 0$, is positive up to $\rho = \rho_M$, then gets negative, and goes to $-\infty$ as $\rho \to 1$. As a result, the size of the intermediate sector expands as the WFH share increases from 0, yet shrinks rapidly when skilled workers converge to full WFH.

Furthermore, differentiating ρ_M with respect to ε shows that it increases with ε if and only if the level of ICT development is high enough, that is, $\phi > 1/\tau$. In this case, a better substitutability between home and office labor ($\varepsilon \uparrow$) increases ρ_M, and thus the intermediate sector expands for a wider range of WFH shares.

Wages. Because the market for unskilled workers is perfectly competitive, they are paid their marginal productivity (up to a constant markdown in the intermediate sector). By contrast, there is no traditional concept of 'marginal productivity' for the skilled workers because they are the residual claimants of net operating profits, $\Pi(p) - (1-\rho)p_b$. However, we can consider that the marginal entrant's net operating profits measure the private value of the marginal variety. Hence, the wage w_s paid

[9] When home and office labor are perfect substitutes ($\varepsilon \to \infty$), $A(\rho)$ is a linear function of ρ, which is maximized at $\rho = 0$ if $\phi < 1/\tau$. In this case, the efficiency of ICT is too low compared to commuting costs so that all tasks are better performed in the office rather than at home.

by firms is proportional to the intermediate firm's net operating profit and, hence, to skilled workers' productivity.

Computing the elasticity of the unskilled wage given by (27) with respect to ρ, we obtain the following expression:

$$\mathcal{E}_\rho(w_\ell) = \frac{1}{\sigma - 1}\mathcal{E}_\rho(A(\rho)) - \frac{\alpha\delta(1-\mu)}{1-\delta}\mathcal{E}_\rho(B). \tag{32}$$

Since $A(\rho)$ is bell-shaped while $\mathcal{E}_\rho(B)$ is decreasing for $\rho > \rho_B$, there exists a unique threshold $\rho_{w_\ell} \leq 1$ such that unskilled wage increases for $\rho < \rho_{w_\ell}$. If $A(\rho)$ decreases moderately for $\rho > \rho_M$, the effect of a decreasing $A(\rho)$ will be more than compensated by the positive effect of a decreasing B, and thus the unskilled wage increases. By contrast, if $|\mathcal{E}_\rho(A(\rho))|$ is sufficiently large at $\rho = 1$, then $\rho_M < \rho_{w_\ell} < 1$ hold because $\mathcal{E}_\rho(B)$ is decreasing and finite for $\rho > \rho_B$. Consequently, *the unskilled wage is bell-shaped with respect to the WFH share.* Note that these results hold when $A(\rho)$ is given by (29) because $\mathcal{E}_\rho(A) \to -\infty$ when $\rho \to 1$.

Using (28), we show in Appendix A.3 that w_s/w_ℓ increases with ρ. In other words, *a higher WFH share exacerbates wage inequality.* Moreover, by definition we have $\mathcal{E}_\rho(w_s) = \mathcal{E}_\rho\left(w_s/w_\ell\right) + \mathcal{E}_\rho(w_\ell)$. Since the first term on the right-hand side is positive, there exists a threshold value $\rho_{w_s} > \rho_{w_\ell}$ such that $\mathcal{E}_\rho(w_s) > 0$ if $\rho < \rho_{w_s}$ and $\mathcal{E}_\rho(w_s) < 0$ otherwise. Note that if $\rho_{w_\ell} = 1$, then the skilled wage always increases with the WFH share, as does the unskilled wage.

To sum up, we have shown the following:

Proposition 2 (WFH and productivity) *If the WFH share is not too large, then a higher ρ raises the productivity and the wage of both skilled and unskilled workers. Furthermore, when $\lim \mathcal{E}_\rho(A(\rho)) \to -\infty$ at $\rho = 1$, the productivity and wage decrease with ρ for both types of workers when the WFH share exceeds some threshold.*

The intuition for the bell-shaped behavior of wages lies in the technology that combines home and office workers. This is especially illuminating when $A(\rho)$ is given by (29). When $\rho > \rho_M$, the efficiency of ICT, captured by ϕ, is too low to sustain a high share of tasks performed home. This generates a negative effect on the intermediate sector whose size shrinks. Combined with a decreasing demand for buildings, this leads to a lower demand for both skilled and unskilled workers, which, in turn, reduces their wages. As a result, an excessive downscaling of office work is bad for productivity and for workers.

By contrast, when ICT are sufficiently efficient (ϕ is large), the mass of firms in the intermediate sector increases. As a result, both the skilled and unskilled wages increase because more varieties in the intermediate sector increase the productivity of the final sector (and hence demand for intermediate goods). Furthermore, for $\phi > 1/\tau$, a better substitutability between home and office labor ($\varepsilon \uparrow$) increases ρ_{w_ℓ} and ρ_{w_s}. Hence, whether WFH has positive or negative consequences for both types of workers depends crucially on the relative efficiency of ICT.

Land rent and the price of buildings. We now turn our attention to the impact of ρ on the price of buildings and the land rent. Using (32), their elasticities are, respectively, given by

$$\mathcal{E}_\rho(r) = \frac{1}{\sigma - 1}\mathcal{E}_\rho(A) + \frac{(1-\mu)(1-\alpha)\delta}{1-\delta}\mathcal{E}_\rho(B), \quad \mathcal{E}_\rho(p_b) = \frac{1}{\sigma - 1}\mathcal{E}_\rho(A) + \delta\frac{(1-\mu)(1-\alpha)}{1-\delta}\mathcal{E}_\rho(B).$$

The above expressions show that, for small values of ρ, both elasticities are positive because $\mathcal{E}_\rho(B) > 0$ and $\mathcal{E}_\rho(M) > 0$. On the other hand, both $\mathcal{E}_\rho(M)$ and $\mathcal{E}_\rho(B)$ are negative at $\rho = 1$. Since $\mathcal{E}_\rho(M)$ changes sign only once while $\mathcal{E}_\rho(B) < 0$ for $\rho > \rho_B$, there exist two values ρ_{p_b} and ρ_r with $0 < \rho_{p_b} < \rho_r < 1$, such that: (i) $0 < \mathcal{E}_\rho(p_b) < \mathcal{E}_\rho(r)$ if $\rho < \rho_{p_b}$; (ii) $\mathcal{E}_\rho(p_b) < 0 < \mathcal{E}_\rho(r)$ if $\rho \in (\rho_{p_b}, \rho_r)$; and (iii) $\mathcal{E}_\rho(p_b) < \mathcal{E}_\rho(r) < 0$ if $\rho > \rho_r$. In words, more WFH first raises the prices of buildings and land due to increased demand for home-office space, and then eventually decreases both as home-office demand stagnates while demand for working-space shrinks. The prices for buildings start decreasing before the prices for land do.

Furthermore, combining the above expressions leads to the following relationship: $\mathcal{E}_\rho(p_b) = \mathcal{E}_\rho(r) - (1-\mu)\mathcal{E}_\rho(B)$. When the supply of land is not perfectly elastic ($\mu < 1$), and given that $\mathcal{E}_\rho(B) < 0$, the building price reacts more to an increase in ρ than the land rent. By contrast, we have $\mathcal{E}_\rho(p_b) = \mathcal{E}_\rho(r)$ when $\mu = 1$. In other words, both building price and land rent are equally affected if and only if the land supply is perfectly elastic; otherwise the land rent r changes faster than the price of buildings p_b.

The following proposition provides a summary.

Proposition 3 (WFH, building price, and land rent) *When the WFH share ρ starts rising from 0, both the land rent and the building price increase. As ρ keeps rising,* *the land rent decreases while the building price increases. Finally, for a sufficiently high ρ, both prices fall.*

How does the aggregate land rent, ALR, change? Computing its elasticity yields $\mathcal{E}_\rho(ALR) = \mathcal{E}_\rho(r) + \mu\mathcal{E}_\rho(B)$. Stated differently, *the landowners benefit from WFH when telecommuting takes off, but their incomes start decreasing beyond some point.* Since $\mathcal{E}_\rho(B) < 0$ for $\rho > \rho_B$, the aggregate land rent varies less than the price of land. These effects are stronger when land is more elastically supplied (larger μ). The reason is that a more elastic land supply translates into a larger housing supply, thereby increasing aggregate land rent (a quantity rather than a price effect).

Residential and commercial buildings. Since we know how the output of the construction sector varies with the WFH share, we can determine how it is distributed between housing (B_h) and the intermediate sector's demand for commercial buildings (B_I). Observe first that, using (2), (5), and (10), the housing output

$$B_h = \left[\gamma \frac{w_s}{w_\ell} \delta^{-\frac{\delta}{1-\delta}} B^{-\frac{(1-\mu)\delta}{1-\delta}} + (1-\gamma)\bar{h}\right] L_s + \gamma \delta^{-\frac{\delta}{1-\delta}} B^{-\frac{(1-\mu)\delta}{1-\delta}} L_\ell,$$

increases with ρ because the wage ratio increases whereas B decreases for $\rho > \rho_B$. Second, since $B_I = B - B_h$, B_I decreases. Therefore, an increasing WFH share leads to higher demand for housing whereas the demand for commercial buildings shrinks. The latter effect dominates the former and the overall output of the construction sector falls.

The impact of commuting costs. Since (26) does not involve τ, the equilibrium output of the construction sector is independent of commuting costs. By contrast, the magnitudes w_s, w_ℓ, p_b, and Y depend on τ via M. More specifically, as M decreases with τ, it follows from (27) that w_ℓ decreases with τ. The skilled wage w_s also decreases with τ and does so at the same rate as w_ℓ because (28) does not involve τ. Using (10) and (25) shows that the equilibrium values of p_b and Y are proportional to the unskilled wage. Hence, both decrease with τ. Note also that (9) implies that the ALR decreases with commuting costs. Thus, *the whole economy shrinks when commuting costs rise as the latter are a pure social loss.* It is, therefore, not surprising that WFH is socially desirable. We show in Section 4.4 that, as expected, the gains from reduced commuting are even larger in the presence of a congestion externality. Though conceptually straightforward, this case is analytically more involved to analyze.

The impact of the land supply elasticity. We relegate the formal analysis of the role of the land supply elasticity μ to Appendix A.4. There, we show that both the price of land, r, and of buildings, p_b, decrease with μ; and that the drop in land prices is larger than the drop in building prices. We also show that all three sectors produce more when the land supply is more elastic, and both skilled and unskilled workers' welfare increases.

In sum, *an undersupply of developable land has negative effects on the whole economy, as well as on individual welfare.* These results are in line with the central finding in urban economics and city planning that restrictive land development and land-use regulations affect firms' productivity and workers' welfare via higher housing prices (Glaeser and Gyourko, 2018).

4.2 The distributional effects of WFH

Changes in the organization of work are likely to trigger sizable macroeconomic effects and vast distributional consequences. We have shown that skilled and unskilled wages need not move in the same direction. We now zoom in on the macroeconomic and distributional impacts of WFH. To this end, we first consider how GDP changes. We then look at how a more direct measure of well-being—skilled and unskilled workers' welfare—changes with ρ.

The Gross Domestic Product (GDP) of the economy is given by the sum of unskilled wages, skilled wages, and the aggregate land rent. Formally, we have $GDP = w_\ell L_\ell + w_s L_s + ALR$. Combining Propositions 1 and 2, there exists a threshold $\rho_{GDP} > \rho_{w_\ell}$ such that the GDP first increases for ρ smaller than ρ_{GDP} and, then, decreases. In other words, *telecommuting boosts the economy when the WFH share is low but hurts the economy once the WFH share is high* when $|\mathcal{E}_\rho(A(1))|$ is sufficiently large.

Since the GDP only partially captures well-being when there are multiple types of agents, we turn our attention to the impact of the WFH share on individual welfare. Consider first the welfare of the unskilled. Substituting p_b, given by (10), into (6) and taking the elasticity of V_ℓ with respect to ρ yields the following expression:

$$\mathcal{E}_\rho(V_\ell) = \frac{1-\gamma}{\sigma-1}\mathcal{E}_\rho(A) - \frac{[\gamma+\alpha(1-\gamma)](1-\mu)\delta}{1-\delta}\mathcal{E}_\rho(B).$$

Using the same argument as for (32), there exists a value ρ_{V_ℓ} such that $\rho_{w_\ell} \leq \rho_{V_\ell} < 1$ and V_ℓ decreases with ρ over $[\rho_{V_\ell}, 1]$.

Consider next the welfare of the skilled. We show in Appendix A.5 that there exists a threshold $\rho_{V_s} > \rho_{w_s}$ such that V_s increases with ρ on (ρ_B, ρ_{V_s}) and decreases for $\rho > \rho_{V_s}$. Hence, skilled welfare falls for either very low or very high WFH shares. The former case is due to the additional consumption of housing space: an extra room for work at home reduces welfare if it has to be paid but saves little commuting costs since the presence in the office remains required most of the time. The latter case arises when $A(\rho)$ decreases steeply at $\rho = 1$. To summarize:

Proposition 4 (WFH, GDP, and welfare) *When* $\lim \mathcal{E}_\rho(A(\rho)) \to -\infty$ *at* $\rho = 1$, *then the WFH share increases, the GDP and the welfare of both types of workers first increase and, then, decrease.*

We can finally look at relative welfare of the two types of workers. Using (6) and (28), we get

$$\frac{V_s}{V_\ell} = \frac{1-(1-\delta)\gamma}{\Gamma}\frac{L_\ell}{L_s} - \frac{((1-\delta)(1-\gamma)+\Gamma)\delta^{\frac{\delta}{1-\delta}}}{\Gamma}(\bar{h}+1-\rho)B^{\frac{(1-\mu)\delta}{1-\delta}}.$$

As implied by (26), $(\bar{h}+1-\rho)B^{\frac{(1-\mu)\delta}{1-\delta}}$ varies in the same way as B. Therefore, for $\rho > \rho_B$, the welfare ratio increases with the WFH share. In other words, *telecommuting has implications for inequality on top of it effects on wages, an aspect that is often absent from the debate about its costs and benefits.*

Wrapping everything up, when firms and workers adopt a WFH strategy, the output of the construction sector expands because of the higher demand stemming from the skilled workers who need more space to work home. Simultaneously, as ICT are under-used, there is entry in the intermediate sector that supplies a wider range in inputs. This in turn enhances the productivity of the final sector. The combination of these effects boosts the entire economy, thus making all workers better off. As the WFH share rises further, the output of the construction sector starts decreasing because the reduced demand for buildings stemming from the intermediate firms overcomes households' additional demand for housing. This triggers a decrease in the unskilled wage. By contrast, the efficiency of the final sector keeps rising because the range of intermediates still widens due to efficient ICT, thus sustaining a further rise in the skilled wage. Beyond the most efficient home-office work combination, the expansion of the intermediate sector slows down because its impact on the final sector increases at a decreasing rate. Eventually, the skilled wage starts decreasing too because ICT are over-used. As a result, fixed costs in the intermediate sector rise, which sparks the exit of intermediate firms and makes the final sector less efficient. This leads to an overall contraction of the economy and a fall in the GDP.

4.3 Where are the tops of the bells?

A recurrent theme of our analysis is the existence of bell-shaped relationships between the WFH share and most economic variables. What is important to policy makers and workers is where the bliss points are. For example, is GDP maximized for a large or small value of the WFH share? How does the welfare gap between skill groups change with the WFH share? And what role do the efficiency of ICTs and the supply elasticity of land play?

We have provided some qualitative answers to these questions in the foregoing sections. We now provide quantitative illustrations. Computing different thresholds on ρ requires giving specific values to the various parameters. For our results to be meaningful, we will use (29) and the following empirically relevant parameter values. First, since our model omits capital, we consolidate the land and capital shares to $\alpha = 0.4$, which amounts to a labor share equal to 0.6; $\gamma = 0.3$ for the housing share of income and $\delta = 0.3$ for the land share in construction (Davis and Ortalo-Magné, 2011; Combes *et al.*, 2019); $\tau = 1.08$, i.e., commuting costs are 8 percent of workers' wages (Redding and Turner, 2015); and $\sigma = 1.5$ for the elasticity of substitution among inputs (Miranda-Pinto, 2021).[10] We choose a share of 33 percent of the labor force for the skilled, which corresponds to the share of college educated in the 2019 Census data (Davis *et al.*, 2021).[11] Last, using recent estimates by Davis *et al.* (2021), we set $\varepsilon = 5$

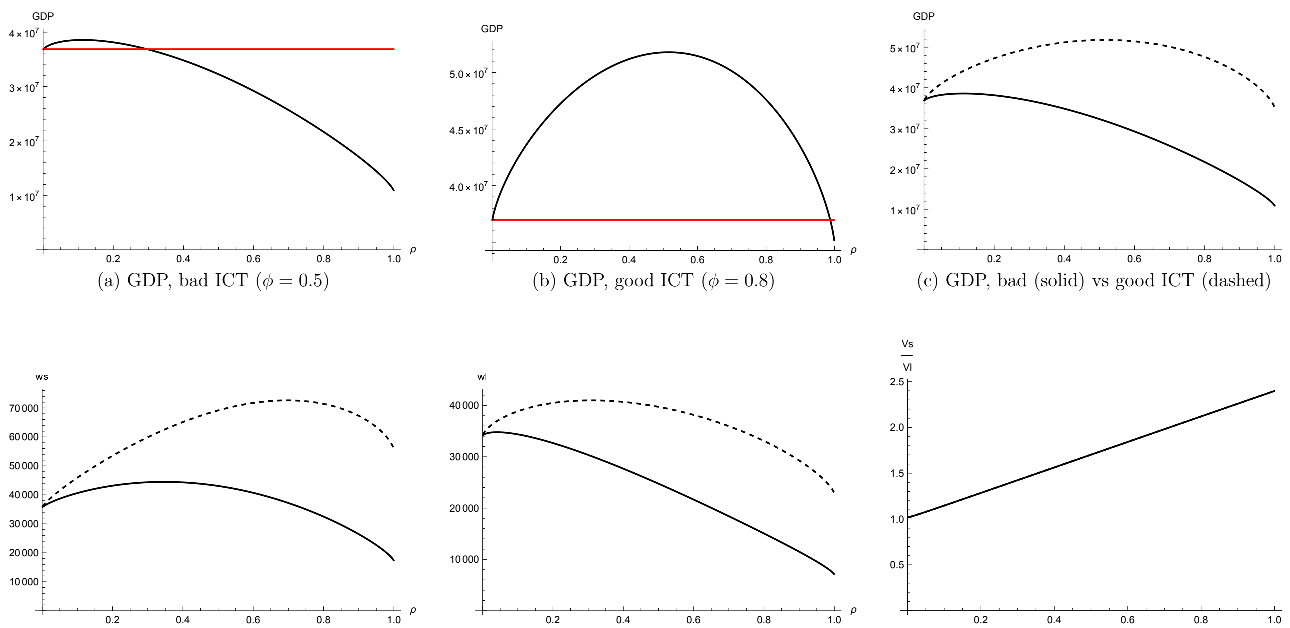
[10]This elasticity of substitution varies a lot across sectors (Miranda-Pinto and Young, 2021).

[11]This share is generous and we view it as an upper bound. Recall that the skilled in our model are required to set up varieties, thus are closer to workers in R&D. Kerr and Robert-Nicoud (2020) report a share of 5 percent of the U.S. labor force for the R&D workers in New York and San Francisco.

for the elasticity of substitution between home- and office-work.

There are a number of remaining parameters for which we have no consensus values. First, concerning the home-office function $\overline{h}(\rho) = k\rho^{\theta}$, we set $\theta = 0.05$ (the elasticity of $\bar{h}$ is small) and $k = 0.05$ for the impact of WFH on housing to be mild. Concerning the fixed costs for creating a variety, we set $F = 1$. Last, we will consider alternative scenarios for the elasticity of land supply, μ, and the efficiency of ICT, ϕ: a less elastic land supply ($\mu = 0.7$) or a more elastic land supply ($\mu = 0.9$); and less efficient ICT ($\phi = 0.5$) and more efficient ICT ($\phi = 0.8$).[12]

Figure 1: Equilibrium outcomes as a function of ρ (more elastic land supply, $\mu = 0.9$)



(a) GDP, bad ICT ($\phi = 0.5$) (b) GDP, good ICT ($\phi = 0.8$) (c) GDP, bad (solid) vs good ICT (dashed)

(d) w_s, bad (solid) vs good ICT (dashed) (e) w_ℓ, bad (solid) vs good ICT (dashed) (f) relative welfare V_s/V_ℓ

Notes: The parameter values are set as indicated in the text.

Panels (a) and (b) of Figure 1 depict GDP as a function of the WFH share ρ. Panel (a) shows that with a relatively inefficient ICT (making WFH relatively less productive), there are gains from WFH compared to the no-WFH case ($\rho = 0$, the red line) until $\rho \approx 0.3$. Beyond that, WFH reduces GDP compared to the full office case. Observe that the GDP-maximizing WFH share is quite low, about $\rho = 0.1$. Panel

[12] Davis *et al.* (2021) estimate $\phi = 0.371$, which strikes us as quite low. We will use it in the robustness checks. Morikawa (2020) reports a WFH productivity of 68.3% compared to the productivity in the office in Japan, which implies $\phi = 0.683$.

(b) shows that with more efficient ICT, WFH is beneficial over a wider range of work arrangements. Only for very large WFH shares ($\rho \approx 1$) does GDP contract compared to the full office case. The GDP-maximizing WFH share is now larger, about $\rho = 0.5$, but too much WFH still reduces GDP compared to the socially optimal WFH share. In a nutshell, while some WFH is desirable and increases GDP compared to the no-WFH case, WFH can be 'too much of a good thing' and reduce GDP beyond some threshold. Panel (c) shows that, quite naturally, better ICT lead to larger GDP and imply a larger GDP-maximizing WFH share.

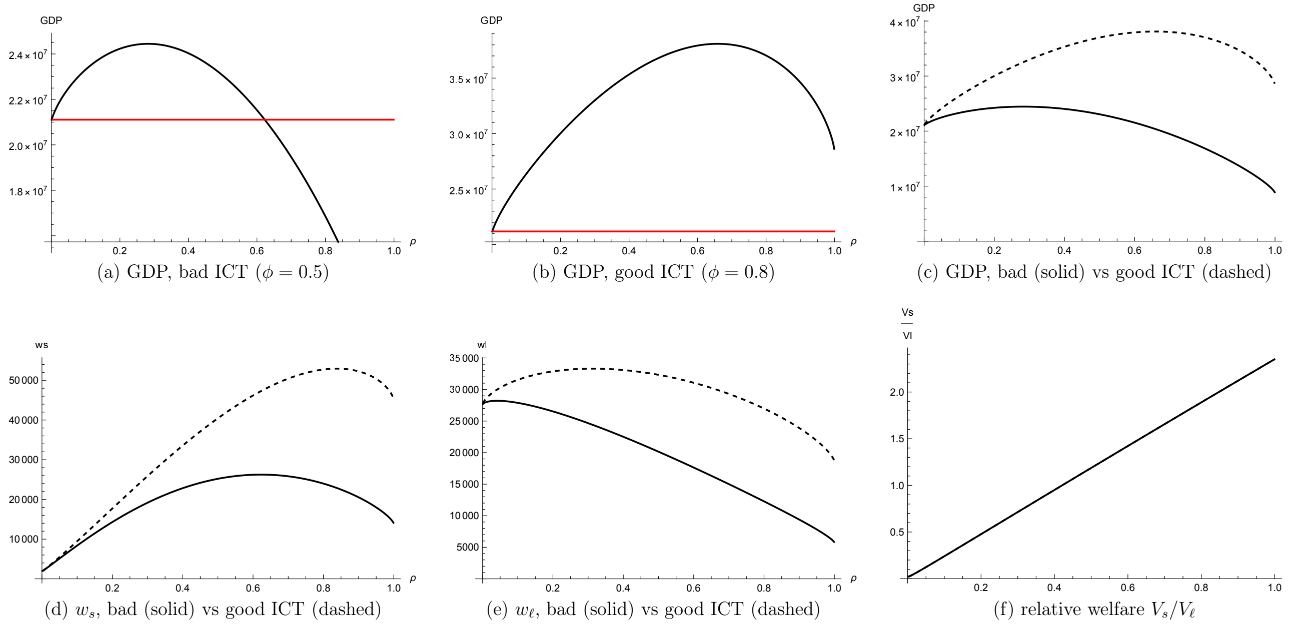
Note that although more efficient ICT permit to efficiently sustain larger WFH shares, we observe that GDP is lower (compared to its maximum value) for small WFH shares; in that case, the potential of advanced ICT is underused. In other words, the adoption of new wired technologies need not be desirable when the WFH share is low. This coordination failure may explain why WFH was low before the Covid pandemic, even though the technology for sustaining larger shares probably existed. Only when a sufficiently large mass of intermediate firms move to a large ρ can the new technology be implemented at efficient scale. *The Covid shock may thus act as a coordination device and shift the economy to a new equilibrium* (Bartik *et al.*, 2020). We develop this point more precisely in Section 5 below when workers are free to choose their preferred value of ρ.

Panels (d) and (e) of Figure 1 depict skilled- and unskilled wages, w_s and w_ℓ. Both curves shift up with improvements in ICT and their maximum shifts to the right, implying that a larger WFH share is desirable. As proven analytically, both wages start to decline beyond some threshold, showing that too much WFH reduces them. The decrease starts earlier for the unskilled than for the skilled. Last, panel (f) shows that relative welfare V_s/V_ℓ increases, thereby implying that the skilled benefit more from more WFH than the unskilled. This is the distributional impact of WFH that we discussed in the previous section.[13]

Figure 2 replicates Figure 1 for the case of a less elastic land supply ($\mu = 0.7$ instead of 0.9). As shown, when the land supply is less elastic, more WFH (larger values of ρ) are more desirable; the GDP-maximizing WFH share shifts to the right and, compared to the no-WFH case (red line) WFH becomes a better option over a larger range of work arrangements. The WFH shares that maximize GDP are now $\rho = 0.227$ in the

[13]We relegate the graphs related to the housing and land markets, B, p_b, and r to Figure 5 in Appendix C.

Figure 2: Equilibrium outcomes as a function of ρ (less elastic land supply, $\mu = 0.7$)



(a) GDP, bad ICT ($\phi = 0.5$)

(b) GDP, good ICT ($\phi = 0.8$)

(c) GDP, bad (solid) vs good ICT (dashed)

(d) w_s, bad (solid) vs good ICT (dashed)

(e) w_ℓ, bad (solid) vs good ICT (dashed)

(f) relative welfare V_s/V_ℓ

Notes: The parameter values are set as indicated in the text.

case of less efficient ICT, and $\rho = 0.625$ in the case of more efficient ICT. The rest of the effects are as before. We may conclude that WFH is especially important in supply-constrained places that benefit from good ICT.

To gauge the effects of WFH on GDP, we look at the change in GDP when moving from an initial WFH share of 10 percent to a share of 90 percent. In the scenario underlying Figure 1, GDP falls by 3.94 percent in the case of good ICT, and by 57.32 percent in the case of bad ICT. In the scenario underlying Figure 2, the corresponding figures are an increase of 20.72 percent and a decrease of 46.36 percent, respectively.

4.4 Robustness checks: Imperfect substitutability between building types and congestion externalities

Imperfect substitutability between building types. Until now, we have considered that land can be used without frictions for either residential, office, or production purposes. This is clearly a simplification. First, land-use regulations create substantial frictions in the conversion of land between alternative uses. Second, even in the absence of such frictions, industrial land must often be decontaminated before it can be redeployed for residential development. This implies that the supply of land cannot be dispatched without substantial frictions between broad competing categories.

We thus now extend the model to the case where land is imperfectly substitutable between alternative uses. More precisely, industrial land can be transformed into residential land (or vice versa) only by incurring some additional cost. To keep the analysis tractable, in what follows we assume that the amount of land available for development increases with the output of the construction sector not anymore as $\mathcal{L} = B^{\mu}$ but instead as follows:

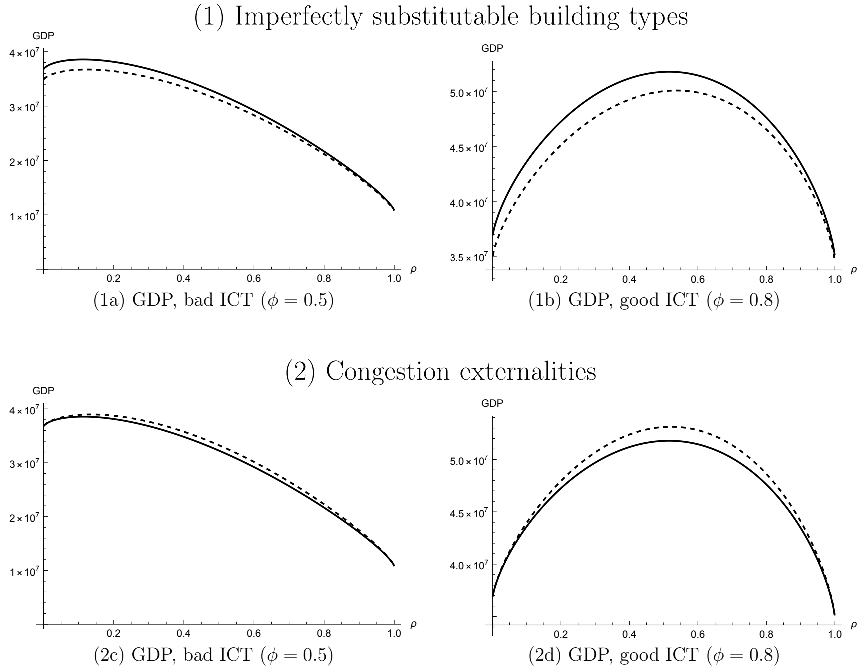
$$\mathcal{L} = \left(B_h^{\zeta} + B_o^{\zeta} + B_p^{\zeta}\right)^{\frac{\mu}{\zeta}},$$

where B_h denotes the demand for housing, B_o the demand for office space, and B_p the demand for production sites (plants). Hence, not only the total demand for land for buildings matters, but also the distribution of demand across types of uses. When $\zeta > 1$ there are frictions between alternative uses, i.e., more land is required to serve the same overall demand: $\zeta \in [1, \infty)$ parametrizes the elasticity of substitution between residential and office buildings. When $\zeta = 1$, land is perfectly fungible across uses and we fall back on our previous analysis. We show in Appendix B how the land rent and prices of buildings are modified in this setting. The rest of the model is identical to that we have analyzed before in the long run.

Panel (1) of Figure 3 depicts simulation results for our baseline set of parameter values. As panels (1a) and (1b) show, frictions in the conversion of land reduce GDP, as expected. Our qualitative conclusions as to the effects of WFH are unaffected by the introduction of these frictions. We also confirm numerically that imperfect substitutability of land between alternative uses reduces both the skilled and the unskilled wages, as well as the ratio of indirect utilities. In a nutshell, all workers are worse off, but the skilled suffer more from the higher land and building prices since they have to consume more costly home-office space.

Congestion externalities. One of the important social benefits of WFH may be reduced congestion due to traffic, which alleviates the social costs of commuting. In our baseline setting, we have abstracted from these costs by considering that τ is independent of ρ. We now relax this assumption and instead assume that $\tau = \tau_0 \mathrm{e}^{-\xi \rho L_s}$, where τ_0 is the baseline commuting costs when $\rho = 0$ (everybody commutes full time to

Figure 3: Equilibrium outcomes, robustness checks (elastic land supply, $\mu = 0.9$)



Notes: The parameter values are set as indicated in the text. In the top panel, the solid curve depicts the baseline case ($\zeta = 1$), whereas the dashed curve makes building types imperfect substitutes ($\zeta = 1.2$). In the bottom panel, the solid curve depicts the baseline case ($\tau = 1.08$ is fixed), whereas the dashed curve includes congestion externalities as explained in the maintext and in footnote 12.

the office) and $\xi > 0$ is a friction parameter that captures the strength of the congestion externality.[14]

Panel (2) of Figure 3 shows that, as expected, the presence of a congestion externality increases the potential GDP gains from WFH and shifts the GDP-maximizing WFH share slightly to the right. In a nutshell, if WFH curbs congestion—i.e., people do not substitute leisure trips for work trips—the potential benefits of more WFH are possibly larger and we should choose a larger WFH share. In particular, the contraction of the economy will arise at a higher value of the WFH share. Analyzing this case is conceptually straightforward. Note, however, that the potential differences seem small given our baseline set of parameter values.

To summarize, neither imperfect substitutability between different types of buildings

[14] We set $\tau_0 = 1.08$ and $\xi = 0.000141$, which implies that when multiplied by our baseline parameter values we have $\tau \approx 1.03$ when $\rho = 1$. In other words, the 'pure commuting costs' are 3% of wages, whereas the 'full commuting costs' τ_0 (including congestion when all workers commute to the office) are 8% of wages.

nor congestion externalities substantially change the general picture that emerges from our numerical simulations. These two elements of the analysis hence appear of second-order importance in our model when compared to the role of ICT and the supply elasticity of land.

5 Equilibrium WFH share

Until now, we have assumed that the WFH share was exogenously given and that changes therein were due to exogenous shocks like a pandemic or technological progress. Let us now assume that either firms or skilled workers choose non-cooperatively their WFH shares in the long run. We will show that these choices are generally not socially optimal and depend on who makes them (firms or workers). We will also show that there are multiple equilibria for workers. Which equilibrium is selected critically depends on the initial configuration of the economy and workers may end up making suboptimal choices.

5.1 Firms choose ρ

Consider that firms play a two-stage game: first, they choose their WFH share ρ; and then, they choose their prices and outputs. Because firms are negligible to the market, they take prices and wages as given when making their decisions. However, as in the case of subgame perfect Nash equilibria, firms anticipate that all others will play their equilibrium strategy and that prices will be consistent with that equilibrium strategy.

Because all firms are identical, we focus on symmetric equilibria only. Since firm i's operating profits and variable production costs are independent of ρ, the profit-maximizing WFH share ρ^* minimizes fixed costs. Since

$$\frac{\mathrm{d}FC_I}{\mathrm{d}\rho} = -\left[p_b + \frac{(1-\rho)p_b + w_s}{\rho}\varepsilon_\rho(A)\right]\frac{F}{A(\rho)}$$

is negative at $\rho = \rho_M$, ρ^* must be larger than ρ_M. When $A(\rho)$ is given by the CES, it is readily verified that

$$0 < \rho^* = \frac{\tau^{\varepsilon-1}\phi^\varepsilon\left(\frac{p_b}{w_s}+1\right)^\varepsilon}{1+\tau^{\varepsilon-1}\phi^\varepsilon\left(\frac{p_b}{w_s}+1\right)^\varepsilon} < 1, \tag{33}$$

which increases with the relative price of buildings to skilled wage, p_b/w_s. By plugging (10) into (33), we obtain the following equation:

$$\rho^* = \frac{\phi^\varepsilon \tau^{\varepsilon-1}\left[\delta^{\frac{\delta}{1-\delta}}\frac{w_\ell(\rho^*)}{w_s(\rho^*)}B(\rho^*)^{\frac{(1-\mu)\delta}{1-\delta}}+1\right]^\varepsilon}{\phi^\varepsilon \tau^{\varepsilon-1}\left[\delta^{\frac{\delta}{1-\delta}}\frac{w_\ell(\rho^*)}{w_s(\rho^*)}B(\rho^*)^{\frac{(1-\mu)\delta}{1-\delta}}+1\right]^\varepsilon+1} \tag{34}$$

whose solution ρ^* is the unique symmetric noncooperative (Nash) equilibrium WFH share. The left-hand side of (34) is equal to 0 at $\rho = 0$ and equal to 1 at $\rho = 1$. As for the right-hand side, it is positive at $\rho = 0$ and smaller than 1 at $\rho = 1$. The intermediate value theorem implies that (34) has at least one solution. Furthermore, the right-hand side may decrease or increase over $(0, \rho_B)$ because the output $B(\rho)$ increases and the wage ratio w_ℓ/w_s decreases. It, however, decreases over $(\rho_B, 1)$ because both the wage ratio w_ℓ/w_s and $B(\rho)$ decrease with ρ. Since the right-hand side is positive at $\rho = 0$, (34) has a unique solution independently of whether the right-hand side decreases or increases over $(0, \rho_B)$. Hence, *there exists a unique symmetric equilibrium WFH rate.* This equilibrium share minimizes firms' total costs at the equilibrium market prices and takes on values that are positive and smaller than 1.

We simulate the model for the baseline case where ρ is exogenously given, and for the case where firms choose it according to (34). We consider the four cases $\mu \in \{0.7, 0.9\}$ and $\phi \in \{0.5, 0.8\}$ as in Section 4.3. All remaining parameter values are set as in our baseline calibration.

Table 1: Firms' optimally choose ρ

Parameters (ϕ, μ)	Chosen value of ρ^*	GDP-maximizing ρ
$(0.5, 0.9)$	0.280	0.113
$(0.5, 0.7)$	0.554	0.283
$(0.8, 0.9)$	0.701	0.516
$(0.8, 0.7)$	0.842	0.659

Notes: The values for all parameters other than μ and ϕ are set as in Section 4.3.

Table 1 summarizes our results. We find that *in all cases firms choose a WFH share that substantially exceeds the value that maximizes GDP.* The intuition underlying this result is easy to grasp: firms disregard the effect of product diversity on productivity in the consumption good sector (recall that the choice of ρ affects product diversity M). Thus, they choose a value of ρ that is not optimal from a social point of view—at least in terms of maximizing the economy's GDP—because they care about private profits (which decrease with the number of competitors) while disregarding the positive externality that a larger mass of intermediates has on the final sector. This is reminiscent of Dixit and Stiglitz (1977) who show that there is insufficient entry in a CES model with a competitive outside sector.

5.2 Skilled workers choose ρ

Consider now the case where skilled workers can choose their WFH share. We may reasonably expect workers to be very heterogeneous in their attitudes toward telecommuting. However, to gain some insights while keeping the analysis simple, we assume here that the skilled are homogeneous. Analogously to the case of firms, workers are negligible to the market so that they take prices and wages per efficiency unit of labor (ω_s) as given when making their decisions. However, workers do understand that their disposable income ($w_s = \rho\omega_s + (1-\rho)\omega_s/\tau$) depends on their choice via the 'home-office space' vs 'commuting costs' trade-off. Finally, as for the case of firms, workers anticipate that all other workers will play their equilibrium strategy and that prices will be consistent with that equilibrium strategy.

Each worker chooses the share ρ that maximizes her welfare. Using the expressions of w_s and $\bar{h} = k\rho^\theta$, skilled welfare (3) takes the following form

$$V_s = \frac{\rho\omega_s + (1-\rho)\omega_s/\tau - p_b k\rho^\theta}{p_b^\gamma}, \tag{35}$$

where ω_s and p_b are taken as given. Differentiating with respect to ρ yields

$$\frac{\partial V_s}{\partial \rho} = \frac{\omega_s(1-1/\tau) - \theta p_b k \rho^{\theta-1}}{p_b^\gamma} = \frac{1}{p_b^\gamma}\left[\frac{\tau-1}{(\tau-1)\rho+1}w_s - \theta p_b k\rho^{\theta-1}\right].$$

We show in Appendix A.6 that V_s is strictly quasi-convex over the interval $[0,1]$ and has two local maximizers at $\rho = 0$ and $\rho = 1$ for all non-negative values of p_b and w_s. Hence, since V_s is ∪-shaped, workers choose either to work full time at the office ($\rho = 0$) or full time at home ($\rho = 1$), depending on whether the benefits of WFH outweigh the additional costs due to housing consumption for work. The intuition for why workers will choose a corner solution ($\rho = 0$ or $\rho = 1$) is easy to grasp. Initially, workers do not want to work only a small share of their time at home because it is associated with additional costs to expand their houses (recall that $\bar{h}$ increases sharply around $\rho = 0$; as explained before, there is a 'fixed cost' nature to acquiring a home office). However, if workers already work part-time home, most of the additional housing costs have been incurred, so that an increase in the WFH share comes at a lower price since $\bar{h}$ becomes flat relatively quickly as ρ increases. Therefore, workers choose to switch to full time WFH as it allows them to save on commuting costs.

Whether welfare is larger at $\rho = 0$ or at $\rho = 1$ is a priori unclear. It depends on many parameters (namely the land supply elasticity μ, the efficiency of ICT ϕ, and commuting costs τ), as well as the values of w_s and p_b that currently prevail in the economy. We hence resort to numerical simulations to illustrate the workings of the model. To this end, we proceed as follows:

(1) We solve the equilibrium (26)–(28) of the model for some given initial value $\rho^0 \in [0, 1]$.

(2) We compute the corresponding equilibrium prices p_b^0 and w_s^0 and evaluate (35) at those prices.

(3) We use $w_s^0 = \rho^0 \omega_s^0 + \frac{(1-\rho^0)\omega_s^0}{\tau}$ to obtain $\omega_s^0 = \frac{\tau w_s^0}{1+\rho^0(\tau-1)}$.

(4) We evaluate $V_s = \frac{\rho\omega_s^0 + (1-\rho)\omega_s^0/\tau - p_b^0 k \rho^\theta}{(p_b^0)^\gamma}$ at $\rho = 1$ and $\rho = 0$. Denote these two values as $V_s(\rho = 1)$ and $V_s(\rho = 0)$.

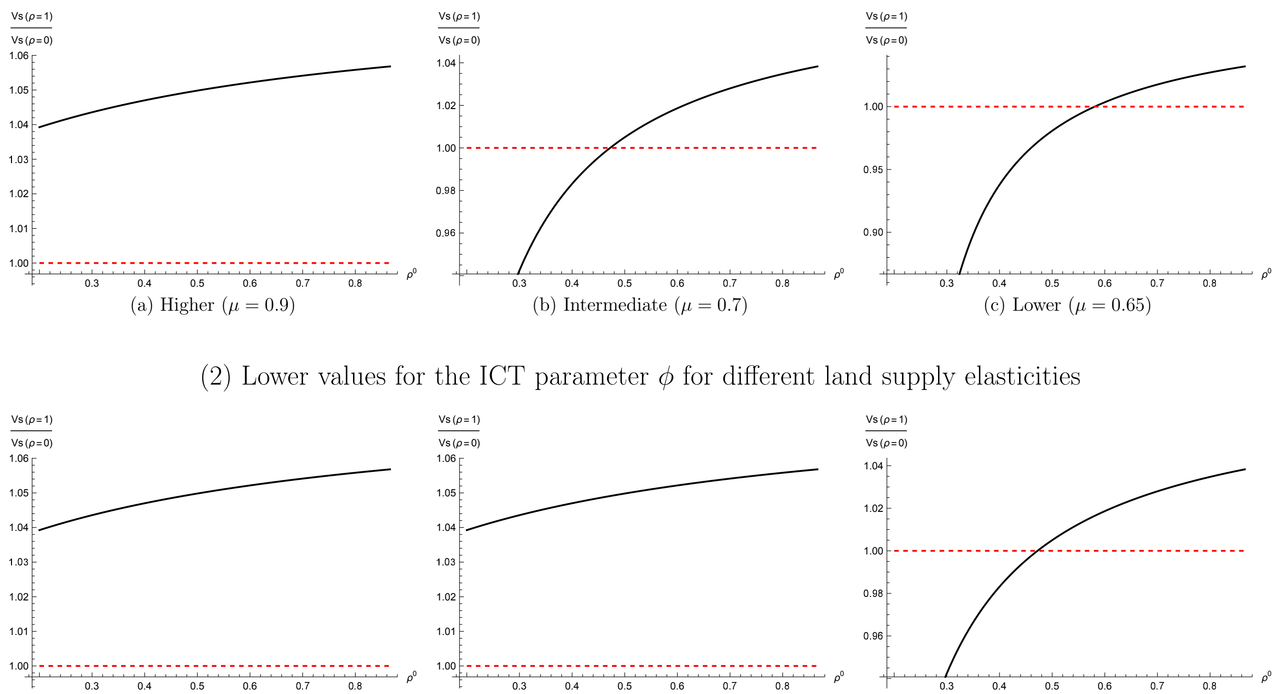
(5) We repeat the process for all $\rho^0 \in [0, 1]$ and depict the ratio $V_s(\rho = 1)/V_s(\rho = 0)$.

(6) If $V_s(\rho = 1)/V_s(\rho = 0) > 1$, workers choose $\rho^* = 1$, whereas they choose $\rho^* = 0$ otherwise.

(7) We evaluate their welfare at the Nash equilibrium by recomputing the prices corresponding to their optimal choices $\rho^* = 0$ or $\rho^* = 1$.

Figure 4 depicts the ratio $V_s(\rho = 1)/V_s(\rho = 0)$ corresponding to the initial equilibrium for all values $\rho^0 \in [0, 1]$. We also depict in red the line corresponding to the case where both are identical (i.e., the ratio equals 1). As explained before, for values above the red line, workers will choose $\rho^* = 1$, and for values below they will choose $\rho^* = 0$. For example, in panel (1b) of Figure 4, a workers will opt for $\rho^* = 1$ if the initial configuration is such that $\rho^0 > 0.48$, and will opt for $\rho^* = 0$ otherwise. Once the

Figure 4: Determination of the Nash equilibrium when skilled workers choose ρ.


(1) Changes in the supply elasticity of land, μ, good ICT ($\phi = 0.8$)

(a) Higher ($\mu = 0.9$) (b) Intermediate ($\mu = 0.7$) (c) Lower ($\mu = 0.65$)

(2) Lower values for the ICT parameter ϕ for different land supply elasticities

(a) Worse ICT, elastic land ($\phi = 0.5$, $\mu = 0.9$) (b) Bad ICT ($\phi = 0.371$, $\mu = 0.9$) (c) Bad ICT, inelastic land ($\phi = 0.371$, $\mu = 0.7$)

Notes: The parameter values are set as indicated in Section 4.3. The value of $\phi = 0.371$ is based on estimates by Davis *et al.* (2021).

equilibrium value of ρ^* is determined, prices adjust to reflect the long-run values that prevail at the Nash equilibrium.

To understand the different cases, consider first panel (1a) of Figure 4. In this case, land is elastically supplied and the communication technology is fairly good. As shown in the figure, whatever the value of ρ^0, workers will choose to work full time at home. When evaluating their welfare at this outcome, we can show that $V_s^*(\rho^* = 1)$ is larger than the welfare that the workers would enjoy if they selected working in the office. The reason is that with an elastic land supply and good communication, the additional cost for a home office is low compared to the savings in commuting costs, while good ICTs imply that there is not a large productivity loss.

Panel (1b) already tells a different story. It suggests that when the supply elasticity of land is lower, the initial conditions matter a lot. If we start from a situation where there is little WFH initially ($\rho^0 < 0.48$), workers will choose $\rho^* = 0$. Only if the initial WFH share is already large will the workers choose $\rho^* = 1$. The intuition is that for a larger initial value of ρ^0, the price of buildings p_b^0 is already lower, thus making expansion of the home office cheaper compared to commuting. If the initial WFH share is too low, additional space is too expensive compared to commuting so that workers will remain in the office. We can show that the equilibrium with $\rho^* = 1$ provides higher welfare than the equilibrium with $\rho^* = 0$. Hence, for $\rho^0 > 0.48$ workers will choose the better equilibrium, whereas they will coordinate on the Pareto-inferior equilibrium if the initial share of WFH is too low.

Last, as shown by panel (1c), the threshold value above which workers will choose $\rho^* = 1$ increases as μ decreases. Hence, for skilled workers to choose WFH we need housing to be sufficiently elastically supplied. In places with low supply elasticities, the extra costs of paying for additional office space at home are only worth incurring if WFH occurs on a sufficiently large scale. This suggests that workers are less willing to work from home in places where housing is very expensive.

Panel (2) of Figure 4 changes the value of the ICT parameter ϕ. In panels (a) and (b), we see that the change in ϕ basically does not change the workers' choice compared to panel (1a). The reason is that workers compare welfare levels at given prices. Hence, that choice mainly depends on how elastic the land supply is. Panel (2a) depicts our baseline case for $\mu = 0.9$ (elastic land supply) and $\phi = 0.5$ (worse ICT). In that case, workers choose $\rho^* = 1$ and that choice provides the better equilibrium. However, when we allow prices to adjust to new equilibria, we have contrasted results depending on the ICT parameter. Indeed, the equilibrium with $\rho^* = 0$ yields almost the same welfare (437.624 versus 437.917). Hence, a slight decrease in the efficiency of ICT below 0.5 will move the workers' choice from $\rho^* = 1$ to $\rho^* = 0$ and they will select the Pareto inferior Nash equilibrium.

This case occurs in panel (2b), where we decrease the ICT parameter to the value reported in Davis *et al.* (2021). In that case, full work at home $\rho^* = 1$ would be chosen irrespective of the starting point. Yet, the equilibrium where everyone works from home yields *lower welfare* than the equilibrium where everyone would go to the office. While it is individually rational to select $\rho^* = 1$, doing so entails substantial productivity losses for the firms, which reduces the number of varieties of intermediate goods and, therefore, the productivity of the final sector. In that case, working from home is 'too much of a good thing' for workers.

Panel (2c) reduces the land supply elasticity while keeping ICT at a quite low level. Comparing with panel (1b), the lower value of ϕ very slightly shifts the threshold value of ρ^0 to the left. Hence, in places with a less elastic land supply and a worse ICT the share of WFH required in the initial equilibrium for workers to choose $\rho^* = 1$ is even a bit larger. However, in that case, the better equilibrium is that where workers spend full time at home, contrary to case (2b) we discussed above.

5.3 Discussion

We have so far little knowledge regarding who will make the choice of the WFH share and how it will be made. Yet, a few insights already emerge from the above. First, firms and skilled workers are likely to make diverging choices. Indeed, the former ignore the consequences of their choices on workers' housing consumption, as well as those on the rate of entry in the innovative sectors. As for the latter, they care about their own welfare and do not account for the productivity gains generated by WFH. The existence of externalities imperfectly mediated by the market makes it hard for firms or workers to get it right. As a result, they will both make suboptimal choices.

Second, our simulation results suggest that the COVID pandemic may act as a 'coordination device' that can shift the economy from one equilibrium to another. Assume indeed that the initial situation corresponds to $\rho^0 = 0.1$, which is about the share of people who worked from home before the pandemic. Assume that the shock moves us to $\rho^0 = 0.75$. In that scenario, in both panels (1a), (1b), and (2c) of Figure 4, if workers could choose they would select to switch from $\rho^* = 0$ to $\rho^* = 1$. Whether that would be the right choice in the long run is a priori unclear, but what is clear is that the exogenous shock can serve as a device that moves us to a long run equilibrium where workers would opt for different work arrangements.

Third, as mentioned above, workers will have very different attitudes toward home-working according to their tasks, family situations, and ages. Likewise, the productivity of a skilled worker may change with the work arrangement in the short and long run. In this respect, it is worth noting that the literature in psychology stresses the importance of an isolation effect when the WFH share is large.

Last, which agents will choose the WFH share is likely to vary across countries and sectors because industries differ in their ability to use wired workers while countries are specialized in different sectors. Furthermore, the institutional contexts specific to each sector and country will also matter. At that stage, it is, therefore, hard to go beyond some general considerations such as those discussed above. The experiences made during the lock-downs generated by the pandemic are too particular to extrapolate what has been learned during a few months.

6 Conclusion

Telecommuting triggers a variety of effects that go far beyond its impact on individual workers' productivity. To study the interplay between these effects, we have developed a general equilibrium model with three sectors and two types of labor that allows us to shed new light on the main trade-offs arising in an economy where WFH is used on a relatively large scale. Our analysis shows that it is profit-maximizing for firms to implement a partial WFH strategy, that is, the working time is split between home and office. At given market prices, the equilibrium WFH share increases with the efficiency of ICT and the relative price of office space. This suggests that telecommuting should keep rising with the development of increasingly efficient communication technologies, especially in high-cost locations. Furthermore, caution is needed because a significant extension of telework will affect market prices and wages in ways that are not always easy to predict. Finally, raising the WFH share has both redistributional consequences and effects for GDP which have so far been put aside. Thus, looking only at the short-run performance of teleworking firms to predict the global impact of WFH provides an incomplete picture of how the economy will be transformed.

Furthermore, we have seen that raising the WFH share has, first, a positive and, then, a negative impact on GDP and incomes. However, labor being probably the most differentiated production factor, implementing a uniform share will likely generate undesirable effects. The best share varies with the occupations and the industries, as well as with workers' individual characteristics. Even though WFH has several desirable effects, e.g., the reduction of congestion and pollutant emissions associated with intensive and long commuting, our results suffice to show that *WFH is not the universal panacea embraced by consulting firms and analysts.*

In this paper, we have used a setting that is too stylized to work out all the effects of WFH. This leads us to mention two important extensions that should be explored in the near future. Our two-location framework must be extended to a multi-location space in order to understand how the structure and composition of cities will be affected by telecommuting. After decades of flight to the suburbs, city centers have again become desirable places where to live. This trend is partly rooted in the shift toward a knowledge-based economy and is embodied in an expanding class of highly-educated and young professionals who work for high-tech, multinational firms, or finance, insurance, and real estate (FIRE). These workers spend a large number of hours at their jobs, which explains their growing distaste for commuting to the workplace and to the amenities they consume (Edlund *et al.*, 2015; Couture and Handbury, 2020). This has fostered the emergence of a wide range of business-to-consumer activities supplied in city centers and produced by low-pay workers (Moretti, 2012). Bloom (2020) predicts that WFH could remove up to 50 percent of spending in city centers. In a detailed study, De Fraja *et al.* (2021) show that WFH should trigger a substantial decrease in unskilled jobs in UK business districts. In other words, WFH could decrease substantially the number of employees in bars, restaurants, and shops. Furthermore, it is important to better understand how changes in demand and supply of housing may affect the urban footprint (sprawl) and the supply of public transportation (which may be negatively affected by sprawl and decreased commuting).

Due to the Covid-19, we have used intensively modern communication technologies to develop and write this paper. Luckily, we had already worked together before and were thus able to leverage substantial tacit knowledge about the team. Despite of this, our experience did not convince us that ICTs are (yet) a great substitute for discussions in the office or around the coffee machine.

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Appendix material

A. Proofs

A.1. Existence and uniqueness of equilibrium.

In this appendix, we prove that there exists a unique equilibrium and show how to determine it. Equations (10), (20), (21) and (23)-(25) form a system of equilibrium equations that determine p_b, M, w_ℓ, w_s, B, and Y:

$$\begin{aligned}
p_b &= \delta^{\frac{\delta}{1-\delta}} w_\ell B^{\frac{(1-\mu)\delta}{1-\delta}} \\
M &= A(\rho)\frac{L_s}{F} \\
w_\ell L_\ell &= (1-\delta)Bp_b + (1-\alpha)\frac{\sigma-1}{\sigma}Y \\
Bp_b &= \gamma(w_\ell L_\ell + w_s L_s) + \alpha\frac{\sigma-1}{\sigma}Y + p_b\left[(1-\gamma)\bar{h} + 1 - \rho\right]L_s \\
1 &= \frac{\sigma}{\sigma-1}M^{-\frac{1}{\sigma-1}} w_\ell^{1-\alpha} p_b^{\alpha} \\
Y &= (1-\gamma)\left[w_\ell L_\ell + \left(w_s - p_b\bar{h}\right)L_s\right] + \delta Bp_b
\end{aligned} \tag{A.1}$$

The system of equations (A.1) can be reduced to the following three equations in the three unknowns B, w_ℓ, and w_s:

$$\underbrace{B^{\frac{1-\delta\mu}{1-\delta}}}_{\equiv F(B)} = \underbrace{\Psi(\bar{h} + 1 - \rho)L_s B^{\frac{(1-\mu)\delta}{1-\delta}} + \frac{\gamma\sigma + \alpha(1-\gamma)(\sigma-1)}{\delta^{\frac{\delta}{1-\delta}}\Gamma}L_\ell}_{\equiv G(B)}, \tag{A.2}$$

$$1 = \delta^{\frac{\alpha\delta}{1-\delta}}\frac{\sigma}{\sigma-1}M^{-\frac{1}{\sigma-1}}B^{\frac{(1-\mu)\alpha\delta}{1-\delta}}w_\ell, \tag{A.3}$$

$$\frac{w_s}{w_\ell} = \frac{1-(1-\delta)\gamma}{\Gamma}\frac{L_\ell}{L_s} - \frac{\delta^{\frac{\delta}{1-\delta}}}{\Gamma}\left[(1-\delta)(1-\gamma)\bar{h} + (\Gamma + (1-\delta)(1-\gamma))(1-\rho)\right]B^{\frac{(1-\mu)\delta}{1-\delta}}, \tag{A.4}$$

where

$$\Gamma \equiv (1-\delta)\gamma + (1-\alpha\delta)(\sigma-1) > 0, \quad \Psi \equiv (1-\gamma)(1-\alpha)(\sigma-1) > 0.$$

Conditions (A.2) and (A.3) are obtained by plugging (10) and (25) into (21) and (23) and rearranging, whereas condition (A.3) is obtained by combining (10) and (24) and using (20). The equilibrium is obtained by solving a block diagonal system of equations. The first block is formed by equations (A.2)-(A.4), which can be solved recursively for B, w_ℓ, and w_s. We first show that (A.2) has a unique positive solution, which is the equilibrium building output B. To this end, observe that $F(B)$ is increasing and convex in B, while $G(B)$ also increases with B but can be either convex ($(1-\mu)\delta > 1-\delta$) or concave ($(1-\mu)\delta < 1-\delta$). Furthermore, $F(0) = 0$ and $G(0) > 0$. Since the exponent of B in $F(B)$ is larger than that in $G(B)$, equation (A.2) has a unique positive solution. Since a higher value of $\bar{h}$ shifts $G(B)$ upward, (26) implies that more buildings are produced when $\bar{h}$ increases. Second, substituting B into (A.3) uniquely yields the equilibrium unskilled wage w_ℓ. Expression (A.3) shows that B and w_ℓ are inversely related: a higher unskilled wage leads to a smaller building output because of higher production costs. Last, substituting B and w_ℓ into (A.4) yields the equilibrium skilled wage w_s (as well as the skilled-unskilled wage ratio, the 'skill premium').

Having obtained the equilibrium values of B, w_ℓ, and w_s, we can retrieve the solutions of the second block of equations one by one. Plugging B and w_ℓ into the equilibrium condition for the construction sector (10), we obtain the equilibrium price p_b of buildings, while the equilibrium output Y of the final sector can be obtained from (25) by substituting p_b, w_s and w_ℓ. Using p_b, w_ℓ, and Y, the size of an intermediate firm is pinned down by (19), while the equilibrium price for intermediate varieties is given by (16). Last, we have seen that M is given by (20).

Since all these equations have a unique solution, *there exists a unique market equilibrium.*

A.2. The skill premium

We now show that the wage ratio exceeds 1, i.e., there is a skill premium, if the ratio L_ℓ/L_snumber of unskilled workers is large enough. Taking the elasticity of (26) with respect to L_ℓ yields

$$\mathcal{E}_{L_\ell}(B) = (1-\delta)\frac{\delta^{\frac{-\delta}{1-\delta}}\frac{\gamma\sigma+\alpha(1-\gamma)(\sigma-1)}{\Gamma}L_\ell}{(1-\delta\mu)B^{\frac{1-\delta\mu}{1-\delta}} - (1-\mu)\delta(\bar{h}+1-\rho)\Psi L_s B^{\frac{(1-\mu)\delta}{1-\delta}}}.$$

Using (26), this becomes:

$$\mathcal{E}_{L_\ell}(B) = \left(\frac{1-\delta}{1-\delta\mu}\right) \frac{\delta^{\frac{-\delta}{1-\delta}} \frac{\gamma\sigma+\alpha(1-\gamma)(\sigma-1)}{\Gamma} L_\ell}{\delta^{\frac{-\delta}{1-\delta}} \frac{\gamma\sigma+\alpha(1-\gamma)(\sigma-1)}{\Gamma} L_\ell + \frac{1-\delta}{1-\delta\mu}(\bar{h}+1-\rho)\Psi L_s B^{\frac{(1-\mu)\delta}{1-\delta}}}.$$

Clearly, we have

$$\mathcal{E}_{L_\ell}(B) < \frac{1-\delta}{1-\delta\mu} < 1.$$

Hence, the second term on the right-hand side of (28) increases less than proportionate with L_ℓ. Since the first term on the right-hand side of (28) increases proportionally with L_ℓ, there exists a number of unskilled workers $\bar{L}_\ell$ such that the inequality $w_s/w_\ell > 1$ holds for any $L_\ell > \bar{L}_\ell$. The equilibrium thus displays a skill premium when the relative endowment of unskilled labor L_ℓ/L_s is sufficiently large. From now on, we assume that this condition holds.

A.3. The wage ratio

Equation (28) may be rewritten as follows:

$$\frac{w_s}{w_\ell} = \frac{1-(1-\delta)\gamma}{\Gamma}\frac{L_\ell}{L_s} - \frac{(1-\delta)(1-\gamma)\delta^{\frac{\delta}{1-\delta}}}{\Gamma}(\bar{h}+1-\rho)B^{\frac{(1-\mu)\delta}{1-\delta}} - \delta^{\frac{\delta}{1-\delta}}(1-\rho)B^{\frac{(1-\mu)\delta}{1-\delta}}. \quad \text{(A.5)}$$

As implied by (26), the second term on the right-hand side of (A.5), $(\bar{h}+1-\rho)B^{\frac{(1-\mu)\delta}{1-\delta}}$ varies in the same way as B, that is, it decreases for $\rho > \rho_B$. The last term on the right hand side also decreases because both $(1-\rho)$ and $B^{\frac{(1-\mu)\delta}{1-\delta}}$ are decreasing functions of ρ. Therefore, the right hand side of (C.1) increases with the WFH share:

$$\mathcal{E}_\rho\left(\frac{w_s}{w_\ell}\right) > 0.$$

A.4. Comparative statics for the land supply elasticity

This appendix summarizes the comparative static results for the land supply elasticity, μ. Using (26) leads to the following elasticity of the building output with respect to μ:

$$\mathcal{E}_\mu(B) = \frac{\mu\delta}{\Lambda}\left[B - (\bar{h}+1-\rho)\Psi L_s\right]\ln B, \quad \text{(A.6)}$$

where $\Lambda \equiv (1-\mu\delta)B - (1-\mu)\delta(\bar{h}+1-\rho)\Psi L_s$. Since the bracketed term is positive due to (26), while $1-\mu\delta > (1-\mu)\delta$ implies $\Lambda > 0$, we have $\mathcal{E}_\mu(B) > 0$ if and only if $B > 1$.

We now show that $B > 1$ when L_ℓ is sufficiently large, so that $\ln B$ is positive. To see this, note that it follows from (26) that $B > 1$ if and only if $F(1) = 1 \leq G(1)$ for all $\rho \in [0,1]$. This inequality is equivalent to

$$1 \leq (k\rho^\theta + 1 - \rho)\Psi L_s + \delta^{\frac{-\delta}{1-\delta}} \frac{\gamma\sigma + \alpha(1-\gamma)(\sigma-1)}{\Gamma} L_\ell \ ,$$

which holds for all $\rho \in [0,1]$ if it is satisfied when $\rho^\theta + 1 - \rho$ is minimized, that is, when $\rho = 0$ or $\rho = 1$. Therefore, $F(1) \leq G(1)$ if

$$1 \leq \Psi L_s + \delta^{\frac{-\delta}{1-\delta}} \frac{\gamma\sigma + \alpha(1-\gamma)(\sigma-1)}{\Psi} L_\ell$$

holds. This inequality is always satisfied when L_ℓ is sufficiently large. In that case, *a more elastic land supply*, e.g., less restrictive land-use regulations, *leads to more built space.*

We now look at the impact of μ on the wage ratio. Taking the elasticity of (28) with respect to μ and using (A.6), we obtain

$$\mathcal{E}_\mu\left(\frac{w_s}{w_\ell}\right) = \frac{\frac{1-(1-\delta)\gamma}{\Gamma}\frac{L_\ell}{L_s} - \frac{w_s}{w_\ell}}{\frac{w_s}{w_\ell}} \frac{\mu\delta}{\Lambda} B \ln B > 0.$$

In other words, the wage ratio rises with μ. This result allows us to determine how wages vary with μ. Using (27), we obtain:

$$\mathcal{E}_\mu(w_\ell) = \frac{\alpha\mu\delta B}{\Lambda} \ln B > 0. \tag{A.7}$$

Since both the income ratio and the unskilled income increase, the skilled wage w_s must increase with μ. Moreover, it does so at a higher rate than w_ℓ. In sum, *a more elastic land supply increases both wages but exacerbates inequality between workers.*

We next use (9), (10) and (A.7) to uncover the impact of μ on building and land prices. Taking the elasticity of these two expressions yields:

$$\mathcal{E}_\mu(p_b) = -\frac{(1-\alpha)\mu\delta}{\Lambda} B \ln B < 0, \qquad \mathcal{E}_\mu(r) = \frac{1-\alpha\delta}{(1-\alpha)\delta}\mathcal{E}_\mu(p_b) < \mathcal{E}_\mu(p_b),$$

where the second inequality holds because $\delta < 1$. Landowners obviously want μ to be small, which gives rise to rent-seeking via lobbying for land-use regulations.

As to the output of the sectors, combining (21) and (25) leads to

$$\left[\frac{1-\delta}{\delta} + (1-\alpha)\frac{\sigma}{\sigma-1}\right] Y = w_\ell L_\ell + \frac{(1-\delta)(1-\gamma)}{\delta}\left[w_\ell L_\ell + \left(w_s - p_b\bar{h}\right) L_s\right].$$

Therefore, the final sector produces more when μ is larger because both wages increase while p_b decreases. Moreover, dividing the last equation by w_ℓ shows that Y/w_ℓ also increases since the wage ratio increases. Combining this with (19) shows that an intermediate firm's output, q, also increases with μ because the mass of intermediate firms M is unaffected by μ.

Recall that GDP is given by:

$$GDP = Y + h_s L_s + h_\ell L_\ell = Y + \gamma(w_\ell L_\ell + w_s L_s) + (1-\gamma)p_b\bar{h}L_s,$$

where we use (2) and (5). The impact of μ on $GDP = w_s L_s + w_\ell L_\ell + \delta B p_b$ is thus generally unclear because both wages and Y increase while p_b decreases with μ.

Finally, let us consider individual welfare. Since $\mathcal{E}_\mu(p_b) < 0$ and $\mathcal{E}_\mu(w_\ell) > 0$, (6) implies that the unskilled are better off. As for the skilled, their welfare (6) is given by $V_s = (w_s - \bar{h}p_b)/p_b^\gamma$, which increases with μ because w_s increases while p_b decreases. In other words, the skilled are also better off because the housing price p_b decreases with μ.

A.5. Skilled welfare.

Using (10) and (28), we have:

$$V_s = \frac{w_s - p_b\bar{h}}{p_b^\gamma} = \frac{(1-(1-\delta)\gamma)\frac{L_\ell}{L_s} - \delta^{\frac{\delta}{1-\delta}}((1-\delta)(1-\gamma)+\Gamma)(\bar{h}+1-\rho)B^{\frac{(1-\mu)\delta}{1-\delta}}}{\Gamma\delta^{\frac{\delta\gamma}{1-\delta}}B^{\frac{(1-\mu)\delta\gamma}{1-\delta}}} w_\ell^{1-\gamma}.$$

As implied by (26), the second term on the right-hand side in the numerator, $(\bar{h} + 1 - \rho)B^{\frac{(1-\mu)\delta}{1-\delta}}$, varies in the same way as B. Therefore, the ratio increases for $\rho > \rho_B$. However, w_ℓ is bell-shaped with $\mathcal{E}_\rho(w_\ell) \to -\infty$ as $\rho \to 1$ when $A(\rho)$ is given by (29). Hence, there exists a unique threshold ρ_{V_s} such that $\mathcal{E}_\rho(V_s) > 0$ if $\rho < \rho_{V_s}$ while $\mathcal{E}_\rho(V_s) < 0$ otherwise.

A.6. Unique intersection and local minimum when the skilled choose ρ.

Differentiating V_s with respect to ρ, holding ω_s and p_b fixed, yields

$$\frac{\partial V_s}{\partial \rho} = \frac{\omega_s(1 - 1/\tau) - \theta p_b k \rho^{\theta-1}}{p_b^\gamma} = \frac{1}{p_b^\gamma}\left[\frac{\tau - 1}{(\tau-1)\rho + 1} w_s - \theta p_b k \rho^{\theta-1}\right].$$

Let $L(\rho) \equiv \frac{\tau-1}{(\tau-1)\rho+1} w_s$ and $R(\rho) \equiv \theta p_b k \rho^{\theta-1}$. We have

$$\frac{\mathrm{d}}{\mathrm{d}\rho} L(\rho) = -\frac{(\tau-1)^2}{(-\rho + \tau\rho + 1)^2} < 0 \quad \text{and} \quad \frac{\mathrm{d}^2}{\mathrm{d}\rho^2} L(\rho) = 2\frac{(\tau-1)^3}{(1 - \rho + \tau\rho)^3} > 0$$

and

$$\frac{\mathrm{d}}{\mathrm{d}\rho} R(\rho) = -k\theta\rho^{\theta-2} p_b (1-\theta) < 0 \quad \text{and} \quad \frac{\mathrm{d}^2}{\mathrm{d}\rho^2} R(\rho) = k\theta\rho^{\theta-2} p_b (1-\theta) > 0$$

Hence, both L and R are decreasing and convex functions of ρ. We further have $0 < R(0) < L(0)$ and $R(1) > L(1) > 0$. The intermediate value theorem implies that the equation $R(\rho) = L(\rho)$ has at least one solution in $[0, 1]$. Since both R and L are decreasing and convex, they have a unique intersection point, which is the unique minimizer of V_s over $(0, 1)$. Hence, V_s is strictly quasi-convex over the interval $[0, 1]$ and has two local maximizers at $\rho = 0$ and $\rho = 1$ for all non-negative values of p_b and w_s.

B. Imperfect substitutability between residential and office buildings

We derive the conditions that change when building types are imperfect substitutes. The land rent is determined by the land market clearing condition:

$$B_o \frac{\partial c_b^o}{\partial r} + B_p \frac{\partial c_b^p}{\partial r} + B_h \frac{\partial c_b^h}{\partial r} = \mathcal{L},$$

where $\partial c_b^i / \partial r$ is the amount of land required to produce one unit of building $i = o, p, h$. The marginal production cost for each type of building (o=office, p=plants, h=housing) equals

$$c_b^o = r^\delta w_\ell^{1-\delta}, \quad c_b^p = r^\delta w_\ell^{1-\delta}, \quad c_b^h = r^\delta w_\ell^{1-\delta}.$$

Equalizing these two yields $\delta \left(w_\ell / r \right)^{1-\delta} \left(B_p + B_o + B_h \right) = \left(B_h^\zeta + B_I^\zeta + B_x^\zeta \right)^{\frac{\mu}{\zeta}}$, which can be solved for the equilibrium land rent as a function of the construction sector's output:

$$r = \left[\frac{\delta w_\ell^{1-\delta} (B_p + B_o + B_h)}{\left(B_h^\zeta + B_p^\zeta + B_o^\zeta \right)^{\frac{\mu}{\zeta}}} \right]^{\frac{1}{1-\delta}}.$$

Perfect competition in the construction sector implies that $p_b^i = p_b$ equals marginal cost:

$$p_b = w_\ell^{1-\delta} r^\delta = \delta^{\frac{\delta}{1-\delta}} w_\ell \left[\frac{B_p + B_o + B_h}{\left(B_h^\zeta + B_p^\zeta + B_o^\zeta \right)^{\frac{\mu}{\zeta}}} \right]^{\frac{\delta}{1-\delta}}.$$

Price is the same for each type of building because costs are the same.

We also need market clearing of the three buildings markets:

$$B_h = \gamma \frac{w_\ell L_\ell + w_s L_s}{p_b} + (1-\gamma) \bar{h} L_s, \quad B_o = (1-\rho) L_s, \quad \text{and} \quad B_p = \alpha \frac{\sigma - 1}{\sigma} \frac{Y}{p_b}.$$

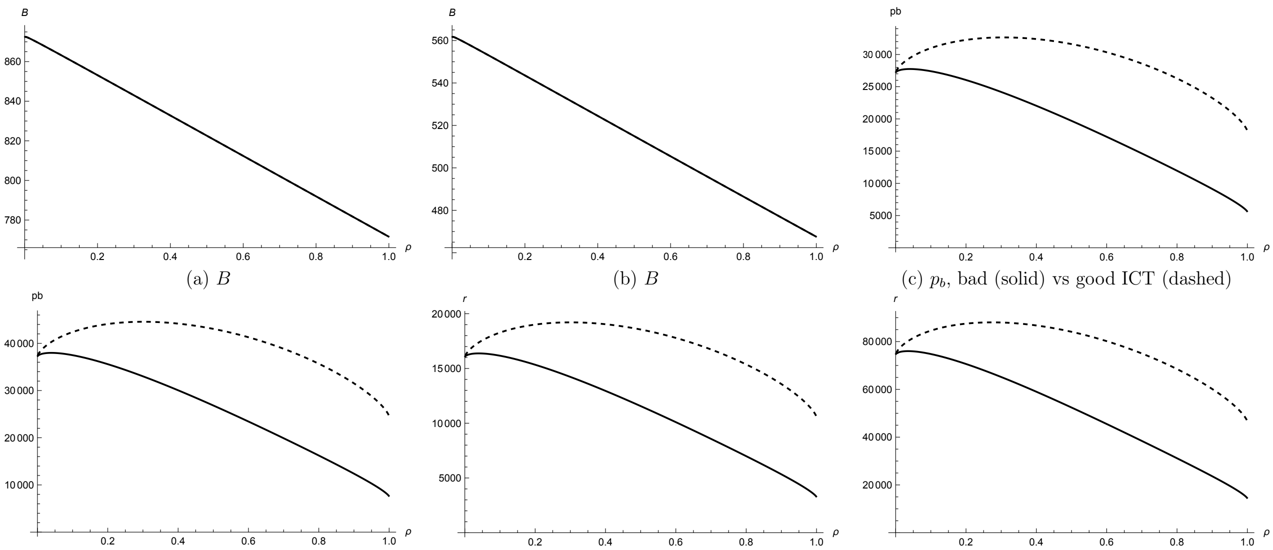
Last, ALR is modified as follows:

$$ALR = r\mathcal{L} = \delta \left[\frac{\delta w_\ell^{1-\delta} (B_p + B_o + B_h)}{\left(B_h^\zeta + B_p^\zeta + B_o^\zeta \right)^{\frac{\mu}{\zeta}}} \right]^{\frac{1}{1-\delta}} \left(B_h^\zeta + B_p^\zeta + B_o^\zeta \right)^{\frac{\mu}{\zeta}}.$$

C. Additional figures

Figure 5 summarizes simulation output for building supply B, as well as land rents r and housing prices p_b. The parameter values are set as in Section 4.3.

Figure 5: Building output, building prices, and land rents.



(a) B (b) B (c) p_b, bad (solid) vs good ICT (dashed)

(d) p_b, bad (solid) vs good ICT (dashed) (e) r, bad (solid) vs good ICT (dashed) (f) r, bad (solid) vs good ICT (dashed)

Notes: The parameter values are set as indicated in the text. The first panel for each variable B, p_b, and r shows results for an elastic land supply ($\mu = 0.9$), while the second panel shows results for a less elastic land supply ($\mu = 0.7$).